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BIOMONITORING PROTOCOLS FOR ADULT AQUATIC INSECTS

R. A. C. PROJECT NO. 322G

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BIOMONITORING PROTOCOLS FOR ADULT AQUATIC INSECTS

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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

EXECUTIVE SUMMARY

The bottom-dwelling immature stages of many aquatic insects (mayflies and caddisflies) are useful indicators of chlorinated organic contaminant (PCBs, pesticides, and petrochemical industrial wastes) concentrations in lakes and rivers. Contaminant concentrations in these animals reflect levels of contaminants in the sediment. However, it is often difficult to obtain adequate material for contaminant analyses using traditional sampling methods, which require specialized equipment and trained personnel. The night-active winged adults of these aquatic insects are strongly attracted to ultraviolet light. We developed techniques for capturing adults with light traps, and evaluated the usefulness of adult aquatic insects as indicators of organic contamination in sediments of Great Lakes connecting channels.

An ultraviolet light trap was developed that collects large numbers (up to 500 g) of adult insects during a 2-h period, without introducing additional contaminants. Light trap samples collected on evenings near lakes and rivers required minimal sorting before being used for contaminant analyses. Air temperature and wind velocity greatly affected sizes of catches. Animals were available in sufficient numbers for contaminant analyses from early June to late August. Attended (2 h collection) and unattended (overnight collection) traps yielded samples containing similar numbers and types of insects. Light trap samples were collected from sites on Great Lakes connecting channels (Detroit, St. Clair, Niagara, and St. Marys rivers) and Lake St. Clair, with known amounts of organic contamination, as well as from nonindustrial reference sites located in Southern and central Ontario (Gull and Ausable rivers, and Balsam Lake). Alternative sampling methods to collect immature animals and freshly emerged adults were also employed, with limited success.

Contaminant analyses by gas chromatography revealed the presence of low but detectable levels of 85% of the contaminants quantified in samples from uncontaminated areas. The highest concentration of individual PCB congeners ranged from 2.2-6.7 ug kg^{-1} in samples from uncontaminated areas. Levels of pesticides were elevated in all samples, regardless of source area. Studies to determine minimum sample size revealed that contaminant analyses of relatively small (1-3 g, fresh weight) samples yielded reliable results. Samples of this size can be collected in southern Ontario from late May until late August. Samples could be stored for at least 8 months at $-20^{o}C$ with no effect on analytical results.

Contaminant concentrations in samples of adult insects corresponded to reported levels of chlorinated organic contaminants in sediments of the rivers and lakes of their origin. Samples from each of the Great Lakes connecting channels contained contaminants characteristic of the source river or lake, both in type and amount. The spatial pattern of contaminants among insect samples reflected the pattern documented for sediments in all connecting channels sampled. Contaminant levels in insects varied with time at the Detroit and St. Clair rivers, presumably following temporal trends in sediment contamination.

Significant differences in contaminant concentrations were found in animals of different species from the same location. Variation in feeding type, lipid content, and particular location of the immature insects on the sediment of lakes or rivers may account for these results. No direct relationship was found between lipid content and contaminant levels of animals. Thus, the variation in contaminant levels among insects of different species cannot be attributed to a single factor.

Dispersal distance studies were conducted to determine the size of area of lake or river from which a single light trap might recruit insects. The resulting dispersal distance estimates of Detroit River caddisflies and Lake St. Clair mayflies showed that 50% of animals in samples originated from a 0.4-3.8 km^2 area, while 90% came from within 4-25 km^2. Most samples collected along Great Lakes connecting channels were composed of species with relatively low dispersal abilities. Comparison of contaminant levels in caddisfly samples collected simultaneously on opposite banks of the Detroit River also suggest that adult insects do not disperse great distances: PCB concentrations in insects collected on the U.S. riverbank were much higher than in those from the Canadian riverbank, corresponding to previously reported local sediment contaminant levels.

Adult aquatic insects are effective alternatives to immature benthic insects or other invertebrates for preliminary surveys of organic contamination in lakes and rivers. We present detailed instructions for collection, processing, and analyses of these animals.

1. INTRODUCTION

Recent research has addressed the potential importance of benthic invertebrates as agents of contaminant transfer between sediments and higher trophic levels in aquatic systems (Larsson 1984, Oliver 1984, Pugsley et al. 1985, Reynoldson 1987, van der Oost et al. 1988). Benthic invertebrates, relatively sedentary organisms, tend to bioaccumulate compounds such that contaminants detected in the tissues of organisms collected in a particular area can be ascribed to sediment contamination in the region of collection. Although aquatic annelids and larval insects are routinely used in laboratory toxicity assays (Scherer 1979), these organisms are employed less frequently as field biomonitors because of their small size and problems in retrieving and processing samples. Molluscs may be collected (and analysed) individually, but they are more sporadic in occurrence than other invertebrates (Pugsley et al. 1985). Diver-assisted collection reduces certain problems, but poor visibility or strong currents make some habitats inaccessible. Thus, several problems exist in monitoring contaminants in aquatic benthic invertebrates:

1. The habitat in which organisms occur is frequently inaccessible, or can be sampled only with specialized equipment by trained personnel. These logistic problems are particularly severe when sampling navigational connecting channels of the Great Lakes or remote locations inaccessible by road.

2. Sampling methods for many invertebrates involve bulk collection of sediments. This necessitates further processing by specialists to obtain sufficient material for analysis. In addition, samples may become degraded and/or contaminated while organisms are sorted.

3. In situ containers that may be used for experimental exposure of organisms in areas of particular interest are subject to loss through storm or vandalism.

Adult insects that have emerged from aquatic habitats have great potential as a biomonitoring tool and provide a cost-effective alternative to sampling organisms directly within the aquatic environment. Mayflies

(Ephemeroptera) and caddisflies (Trichoptera) spend most of their life as larvae, within or in contact with the sediments. The night-active, winged adults emerge during the summer in large numbers. Adults are shortlived, typically do not feed or defecate, and with the exception of a small proportion of contaminants shed with the larval skin (Larsson 1984), body burdens remain unchanged following emergence.

The retention and subsequent transport of naturally accumulated contaminants by dispersing adults has received surprisingly little attention by researchers. Mauck and Olson (1977) and Clements and Kawatski (1984) analyzed adults of the mayfly Hexagenia, and found elevated concentrations of polychlorinated biphenyls (PCBs), indicative of local sediment contamination. Larsson (1984) demonstrated that midges (Diptera: Chironomidae) reared in PCB-contaminated sediments contained high amounts of PCBs as adults. Ciborowski and Corkum (1988) used ultraviolet (UV) light to attract and collect adult Trichoptera and Ephemeroptera from sites along the Detroit and St. Clair rivers. Elevated concentrations of organochlorine compounds and PCBs were detected in adult insects from all sites. Spatial trends in these samples corresponded with earlier workers' assessments of local sediment and water contamination (Thornley and Hamdy 1984, Kauss and Hamdy 1985, Pugsley et al. 1985).

Use of light-trapped adults of aquatic insects to evaluate local contamination can potentially circumvent many difficulties associated with aquatic sampling in that little specialized equipment is necessary for collection, animals are not collected together with surrounding sediments, and large numbers of animals can be quickly acquired and sorted by relatively untrained personnel.

1.1. OBJECTIVES

The objective of this study was to develop standard protocols for collection and analysis of adult aquatic insects for organochlorine contaminants (PCBs, organochlorine pesticides, and petrochemical industry byproducts). Our specific objectives were the following:

1) development of efficient collection techniques, notably
   i) unattended light traps for adults;
   ii) collection of adults in the process of emerging;

2) measurement of dispersal distance of adults and evaluation of dispersal effects on perceived local contaminant levels;

3) evaluation of seasonal variation in adult insect abundance and contaminant levels along the Lake Huron/Lake Erie Connecting Channel;

4) determination of inherent variability among replicates and minimum sample size necessary for adequate detection of contaminants;

5) comparison of contaminant levels in adults collected from contaminated and clean water habitats;

6) validation of sampling methods by evaluating organic contaminant levels in other "Areas of Concern" within the Great Lakes Basin.

2. MATERIALS AND METHODS

2.1 Life Cycles of Trichoptera and Ephemeroptera

Life cycles of aquatic insects generally consist of a brief (several months) to an extended (1-2 years) aquatic larval period, followed by a short (several hours-30 days) terrestrial winged adult stage. The taxa most frequently attracted to light traps are Ephemeroptera, Trichoptera, Coleoptera, and Diptera (Chironomidae). Of these, the first two make up the majority of total biomass.

Mayflies (Ephemeroptera) are hemimetabolous insects and lack a pupal stage. Larvae (nymphs) undergo 12-45 instars (Merritt and Cummins 1978). At the end of the larval period (1-3 years for Hexagenia, <1 year for Caenis) the mature larva swims to the surface and the immature winged adult, the subimago, emerges from the nymphal skin. The subimago flies to land and rests on vegetation until it molts to the imago, the sexually mature adult stage. Adults mate at dusk by swarming, followed immediately by oviposition (Edmunds et al. 1976). Length of the adult stage is 1-3 days. The digestive system of subimagoes and imagoes is vestigial, and the adults do not feed or defecate.

Caddisflies (Trichoptera) are holometabolous. They undergo 5 larval instars, a pupal stage, and a winged adult stage (Merritt and Cummins 1984). Adults mate by swarming following emergence, and fertilized eggs often require several days of maturation before oviposition (Ross 1944). Adult caddisflies are nocturnally active and spend the day resting on vegetation. Hydropsychidae and Leptoceridae are generally univoltine, overwinter as larvae and emerge throughout the summer months. Some species of Hydropsychidae have an additional generation, emerging at the end of summer, which has developed from eggs laid in early summer (Mackay 1978). Although adults have non-

functional digestive systems and neither feed nor defecate, some species of caddisflies (notably Limnephilidae) may ingest liquids and live for up to 30 days (Ross 1944).

2.2. Sample Collection

Aquatic insects were collected over three summers (1987-1989), and a total of 218 insect samples were analyzed for contaminants. Light traps were used to collect most of our samples, although other sampling techniques were also employed to collect emerging and larval insects.

2.2.1. Light Trap Design and Operation

Organochlorine contaminant analysis requires up to 5 g (30-600 insects) of animal tissue. Therefore, efficient collection techniques are essential to ensure availability of adequate material for contaminant analyses. Ultraviolet light traps have been used previously to collect large numbers of insects (Frost 1957), but these traps typically use reservoirs containing organic solvents to immobilize and preserve captured insects. Such methods were unsuitable for samples collected for subsequent analysis using gas chromatography (GC). For our studies, we modified the design of a standard Pennsylvania-type light trap (Frost 1957) by replacing the glass killing jar with a cylindrical reservoir made of aluminum hardware cloth, and using dry ice as the killing/preserving agent.

Our traps (Fig. 1) consisted of a galvanized iron bucket (top diameter 30 cm), with a 12 cm wide cylindrical aluminum hardware cloth reservoir placed in the centre. Dry ice, (approximately 1 kg h^{-1} of operation) was packed around the reservoir. The release of CO_2 gas quickly anaesthetized trapped insects and the ice itself rapidly cooled (or froze) the sample. The reservoir prevented direct contact between animals and the dry ice. The mouth of the

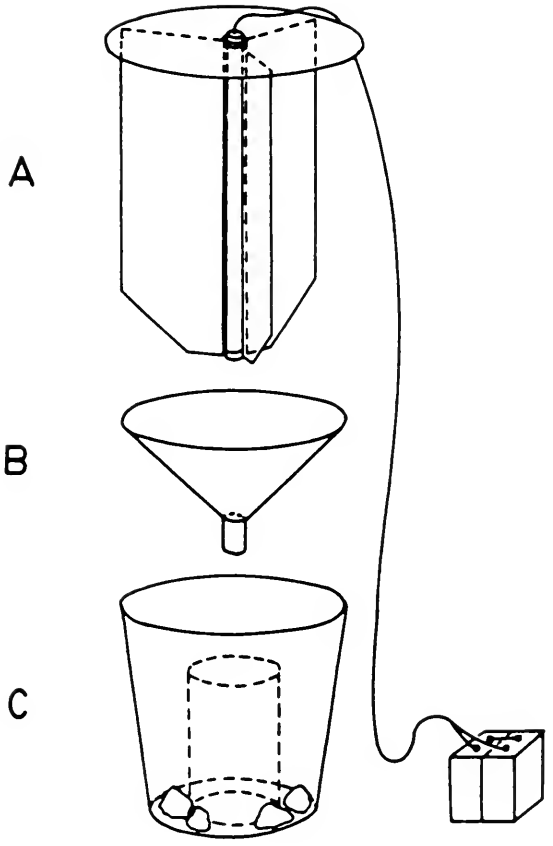

Figure 1. Components of light trap. **A**, light assembly consisting of circular metal top plate, vanes and 12VDC/15W UV flourescent lamp; **B**, funnel; **C**, pail containing metal window screen cylinder and dry ice.

bucket was covered by a large funnel that emptied into the reservoir. The funnel was clipped into the bucket and secured by three metal flanges. A set of three 45 cm tall, 15 cm wide, clear styrene vanes was mounted on the top of the funnel. The vanes were attached to a circular aluminum top plate. A 3 cm diameter hole in the top plate permitted placement and removal of a 45 cm long 12V/15W DC fluorescent long wave ultraviolet lamp (BioQuip^{R} Inc.) at the axis of the vanes. The light was powered by two 6V lantern batteries connected in series, or by an automobile battery. The lantern batteries provided approximately 9 h of continuous service. Traps were precleaned with soap and water before use, and other parts with which the insects could come into contact were hexane-rinsed.

Light traps were placed on a white cotton bedsheet spread on the ground, approximately 2-5 m from the riverbank or lakeshore. Traps were operated for 2 h following sunset, since nocturnally active aquatic insects exhibit greatest flight activity during this period (Nimmo 1966). Most insects attracted by the light flew towards the trap, collided with the vanes and fell into the funnel, which guided them into the reservoir. The sheet served as a light reflector and as a substrate for those insects that failed to enter the trap. Mayflies (Ephemeroptera) tended to alight and remain on the sheet rather than entering the trap. They were grasped by the wings and placed into separate sample jars or were manually added to the trap reservoir.

At the end of the 2-h sampling period, the light was turned off and the contents of the reservoir were emptied into one or more precleaned 500-mL amber glass specimen jars. The sheet was quickly folded to retain any insects that had landed on it. The specimen jars and the folded sheet were kept in a cooler containing dry ice during transport to the laboratory. Samples (including those in the folded sheet) were stored at -20^{o}C prior to sorting.

Animals were removed from the sheet on the morning following collection and were added to the sample jar.

2.2.2. Sample Processing

Samples were weighed, and sorted by taxon at room temperature using hexane-rinsed forceps. Ephemeroptera and Trichoptera were separated from other insects (mostly Diptera and Coleoptera) and were further sorted. The mayflies Hexagenia and Caenis were separated from other mayflies. Caddisflies were identified as Hydropsychidae and "other" Trichoptera (mostly Leptoceridae). Sorting adequate numbers of animals of desired taxa for GC analysis required approximately 1-2 h per sample. Sorting time increased with increasing diversity. One hundred randomly selected caddisflies from each sample were retained (preserved in 70% ethanol) and were later identified to genus. Taxonomic identifications were made using standard references (Trichoptera, Ross 1944, Wiggins 1977, Schmid 1980, Schefter and Wiggins 1986; Ephemeroptera, Needham et al. 1935, Edmunds et al. 1976, McCafferty 1976). Samples awaiting contaminant analysis were wrapped in hexane-rinsed aluminum foil packets and were stored at -20 or -70°C.

Samples of Hydropsychidae, Hexagenia, and, when insufficient Hydropsychidae were collected, mixed Trichoptera were analyzed for contaminants by GC. Hydropsychidae were preferred for analyses since this taxon of caddisflies was consistently the most abundant aquatic insect family in all of our samples collected near rivers. In addition, all hydropsychids are filter-feeders, have similar life cycles, and can be separated from representatives of other families of caddisflies with relative ease without the aid of a microscope. Hexagenia (Ephemeroptera: Ephemeridae) was selected due to its large size, the sediment-burrowing habit of its larvae resulting in

direct exposure to contaminants, and unlimited availability during its emergence period. Hexagenia larvae are known to accumulate organochlorine contaminants and adults have been used as field biomonitors by previous studies (Mauck and Olson 1977, Clements and Kawatski 1984, Ciborowski and Corkum 1988). Two species of Hexagenia (H. rigida McDunnough and H. limbata (Serville)) were collected along the Lake Erie-Lake Huron corridor. Identification of Hexagenia specimens used for contaminant analyses to species was not possible due to the difficulties associated with species identification of females, the low numbers of males, and occasionally, the poor condition of collected animals.

2.2.3. Collection of Emerging Adults

Although adults are easily collected using light traps from land-based stations, catches represent the integrated contribution of individuals from a potentially extensive area. If local benthic densities of immature insects are high, we anticipated that it may be possible to collect adequate material by trapping adults directly as they emerge from their larval habitat. This would provide a better indication of site-to-site variation in contaminant levels. Comparison of adult contaminant estimates with estimated levels in sediments and in larvae from those sediments would provide valuable information regarding rates of bioaccumulation, and on the effectiveness of sampling larvae. We evaluated three methods of procuring animals in situ on Lake St. Clair: a) scoop netting of Hexagenia subimagoes that had recently risen to the water surface; b) use of submersed unattended light traps to attract and capture night-active larvae; and c) use of boat-mounted, attended light traps.

2.2.3.1. Scoop Netting

Scoop netting of recently emerged, floating adults was attempted on the evenings of 22 June and 4 July, 1988, at a location on southeastern Lake St.

Clair (42°20'00"N, 82°27'30"W) from which contaminant data in sediments and Hexagenia nymphs had previously been collected (station 10 of Pugsley et al. 1985, Bedard (1990). Adults had been observed emerging at this site. Standard longhandled D-frame dipnets of 1 mm mesh size were used to capture emerging subimagoes.

2.2.3.2. Submersed Traps for Larvae.

We employed BioQuip^{R} submersible aquatic light traps on 22 June and 4 July 1988, and on 9 July 1989, to determine whether mature, pre-emergent Hexagenia larvae could be attracted in numbers sufficient for GC analysis. Light for the trap was provided by means of Cyalume^{R}, sealed-unit cold light sticks placed within the traps. At sunset, traps were ballasted with an anchor and were lowered to the bottom (water depth 3 m) at the site in southeastern Lake St. Clair used for scoop-netting trials. Maximum nocturnal activity of larval aquatic insects typically occurs during a brief period following sunset, with subsequent peaks sometimes appearing at midnight (standard time) and just prior to dawn (Waters 1972, Müller 1974). Our traps were submersed from 30 min preceding until 2 h following sunset.

2.2.3.3. Boat-mounted Light Traps.

Boat-mounted light traps were used on the evenings of 22 June and 4 July 1988, in southeastern Lake St. Clair. Traps were erected aboard an 8-m inboard motor boat. In June, the boat was anchored at the site in southeastern Lake St. Clair used for scoop-netting. A second location at lake centre, south of the commercial shipping channel was selected for the 4 July study (42°26'15"N,82°25'00"W). In both cases, Peterson grab samples indicated that the substrate was of a texture suitable for Hexagenia development. Sampling was initiated at sunset and continued for 2 h. Adequate numbers of

Trichoptera and Hexagenia imagoes for analysis of 3 replicates of each taxon by GC were acquired. Three replicates of Hexagenia subimagoes were also analyzed to compare contaminant concentrations in the different development stages of this animal.

2.2.4. Collection of Bottom-dwelling Larvae

Hexagenia larvae were collected on several occasions in different years with limited success. Ekman and Peterson grabs were used to sample large amounts of sediment suitable for larvae of Hexagenia. The sediment was sieved to separate the animals from the substrate.

Larvae of filter-feeding caddisflies (Hydropsychidae) were collected from the Detroit River using two different methods. Hexane-rinsed aluminum screening of 1 cm mesh size was lowered into the river in an area with substantial flow, and larvae were allowed to colonize the screening for 10 days. Animals were recovered from the screening using hexane-rinsed forceps. Additionally, larvae were removed from submerged rocks and pieces of concrete near shore. The species collected in greatest numbers was identified (Schefter and Wiggins 1986), and adults of the same species were separated from light trap catches at the same site. Two replicate samples of larvae and three replicates of adults of Hydropsyche alterans (Walker) were analyzed by GC.

2.3. Contaminant Analyses

2.3.1. Laboratory Procedures

Sizes of samples used for site comparisons ranged from 2-5 g fresh weight, depending on availability. Dry weights of samples used for GC analysis were estimated by weighing a 2-5 g portion of the fresh or frozen sample, drying at 105°C for 24 h, and reweighing. Dry weights were then calculated by multiplying the fresh weight of the sample to be analyzed by the

dry weight:fresh weight ratio. All weights were determined to the nearest 0.1 mg using a Sartorius (model R160D) electromechanical balance.

Extractions and contaminant analyses were performed at the Great Lakes Institute analytical laboratory, University of Windsor. Samples were homogenized with mortar and pestle in 50 g Na_2SO_4. Contaminants and lipids were extracted by solid-liquid column extraction using 20 g Na_2SO_4 and 300 mL 50% dichloromethane (DCM)-50% hexane mixture as the solvent. The resulting extract was concentrated to 5 mL in a rotary evaporator and added to a Biobeads column (S-X3, 200-400 mesh, Bio-Rad Laboratories). Two fractions were eluted with 300 mL 45% DCM-55% hexane mixture. Solvent was evaporated from the first fraction and the remaining lipid residue was weighed. The second fraction, which contained all extracted OC compounds, was concentrated to 2 mL by rotary evaporator and cleaned by passage through a column containing 8 g Florisil (60/100 mesh, overlain with 1 g Na_2SO_4). Fraction 1, eluted with 52 mL of hexane, was additionally concentrated to 2 mL. Fraction 2 was eluted with 65 mL 50% DCM-50% hexane and concentrated similarly. One uL from each fraction was injected into the GC (Hewlett-Packard, model 5790A) equipped with a 25 m x 0.25 mm fused silica column and an electron capture detector. Specific conditions and methodology used during GC analyses were as outlined by Ciborowski and Corkum (1988).

In 1987, concentrations of 29 contaminants (18 PCB congeners, pentachlorobenzene (QCB), hexachlorobenzene (HCB), octachlorostyrene (OCS), and 8 organochlorine pesticides were quantified based on peak patterns, and comparison to peaks in standard mixes of known concentrations (Appendix 2). Seven additional PCB congeners were quantified in 1988 and 1989 (Appendix 2). Recovery efficiencies of >90 % were obtained using reference samples spiked with specific concentrations of standard mixes.

2.3.2 Data analysis

Concentrations of individual contaminants in aquatic insect samples were not independent of one another. High correlations were noted among concentrations of all PCB congeners. Accordingly, principal component analysis (PCA) was used to identify groups of associated compounds. Log_e transformed contaminant concentrations in caddisfly and mayfly adult samples collected for site comparisons during years 1 and 2 of our study were used for the analysis. Compounds exhibiting high variation among replicates (coefficient of variation >50%, n=3) were excluded from the analysis. The analysis distinguished 3 independent groups of contaminants (Table 1):

1. PCBs (all quantified congeners, except no. 44) and the pesticide DDE;
2. Pesticides (heptachlor epoxide, dieldrin, and α-BHC);
3. Other organochlorine compounds (octachlorostyrene (OCS), hexachlorobenzene (HCB), and pentachlorobenzene (QCB) and PCB 44.

Concentrations of contaminants within groups were highly correlated with one another. To simplify presentation of our results, we selected 4 representative compounds (Table 1), which were used for comparisons of contaminated and uncontaminated sites. Descriptive statistics for the full data set are presented in Appendix 2.

To explore the relationships between concentrations of OC contaminants in animals captured from all sampling stations, principal component (PC) scores were used as data for clustering analysis (hierarchical agglomerative clustering of Euclidean distances using Ward's method, (Wishart 1987)). Since the relative magnitude of PC scores is representative of concentrations of contaminants associated with that component, we plotted mean PC scores of samples comprising each of the clusters. One-way analysis of variance (ANOVA) followed by Student-Newman-Keuls test (Sokal and Rohlf 1981) was used to

Table 1. Correlation between concentration of organochlorine contaminants and principal components for all samples collected in 1987 and 1988. PCB numbering follows Ballschmiter and Zell (1980).

Compounds (No. of chlorine atoms)	PC-1	PC-2	PC-3
PCB 182 (7)	**0.964**	-0.134	0.006
* PCB 180 (7)	**0.960**	-0.045	0.069
PCB 141 (6)	**0.947**	-0.041	0.076
PCB 170 (7)	**0.943**	0.024	0.055
PCB 138 (6)	**0.939**	-0.008	0.126
PCB 201 (8)	**0.937**	-0.099	-0.042
PCB 101 (5)	**0.932**	0.001	0.188
PCB 153 (6)	**0.932**	-0.023	0.196
PCB 203 (8)	**0.925**	0.007	-0.020
PCB 151 (6)	**0.919**	-0.019	0.118
PCB 110 (5)	**0.884**	0.088	0.246
PCB 194 (8)	**0.883**	0.019	0.047
PCB 118 (5)	**0.882**	0.094	0.112
PCB 70 (4)	**0.872**	0.093	0.198
* PCB 66 (4)	**0.868**	0.109	0.276
PCB 52 (4)	**0.857**	0.073	0.307
PCB 87 (5)	**0.855**	0.091	0.280
PCB 97 (5)	**0.822**	0.079	0.396
DDE	**0.750**	-0.002	0.279
PCB 44 (4)	**0.501**	0.477	0.269
* HCB	-0.079	**0.903**	0.336
QCB	0.013	**0.787**	0.278
OCS	0.306	**0.645**	-0.139
HEPTACHLOR EPOXIDE	0.455	0.024	**0.739**
α-BHC	-0.109	0.392	**0.680**
* DIELDRIN	0.608	-0.082	**0.596**

* Representative compounds

compare mean PC scores of samples in different clusters.

2.4 Specific studies

2.4.1 Detection limits in uncontaminated samples

To establish whether contaminant concentrations in insects correspond to the degree of contamination at the sampling station, one must determine if animals from uncontaminated areas have correspondingly lower contaminant levels. Reference sites were selected in regions free of industrial and agricultural activity to provide baseline contamination data in animals from uncontaminated areas.

Samples were collected from waterbodies in southern and central Ontario (Table 2) for detection limit studies and comparison of contaminant concentrations to those in samples collected at Great Lakes connecting channel sites. Adult insects were light trapped in central Ontario (18-19 June and 6-7 August 1987) from the Gull River at Horseshoe Dam, near the town of Minden (Hydropsyche), at Balsam Lake (Hexagenia), and at Lake Scugog (Caenis). One additional trichopteran sample was taken from downstream reaches of the Ausable River, near Arkona (southwestern Ontario), 17 August 1987. This river supports high densities of aquatic insects and is relatively unaffected by industrial effluents, but receives agricultural runoff. Three replicate samples of adult insects were analyzed for contaminants from each river or lake. In addition, a large sample of Hydropsyche collected at the Gull River was used for minimum sample size determination and storage temperature comparisons.

2.4.2 Minimum sample size

Samples collected at contaminated (Detroit River at Windsor, Ontario) and reference (Gull River, central Ontario) sites (Table 2) were analyzed to determine minimum sample size yielding acceptable variation in contaminant

Table 2. Locations of stations sampled during the seasonal variation and detection limits studies.

Stn	River or Lake	Designation	Latitude (North)	Longitude (West)
1	Detroit R.	River Canard	42°11'48"	83°06'13"
2	Detroit R.	East Windsor	42°20'27"	82°56'56"
3	St. Clair R.	Sombra	42°42'02"	82°29'03"
4	St. Clair R.	Sarnia	42°54'12"	82°27'29"
-	Ausable R.	Ausable R.	43°05'10"	81°48'47"
-	Gull R.	Gull R.	44°58'11"	78°40'58"
-	Balsam L.	Balsam L.	44°34'46"	78°47'02"
	Scugog L.	Scugog L.	44°09'37"	78°49'02"

concentrations among triplicate subsamples. Increasing weights (0.09, 0.18, 0.38, 0.75, 1.5 g dry wt.) of animals were analyzed and separate coefficients of variation were calculated for each contaminant quantified. These coefficients were plotted against sample dry weight. The weight at which the median coefficient of variation reached an asymptote was considered to be the minimum sample weight that yielded acceptable degree of variation. Estimates of minimum acceptable sample size generated for samples from contaminated and uncontaminated areas were contrasted.

2.4.3 Storage time and temperature

Since samples are often not analyzed for contaminants immediately following collection, it is important to determine the most appropriate and efficient storage technique. The effect of storage temperature was evaluated by analyzing insects collected at a contaminated Detroit River site (Windsor) and at a central Ontario reference site (Gull River). Samples were split and stored at different temperatures (-20 and -70°C) for 5-6 mo. Portions of a large (280 g) sample of Hexagenia (Detroit River, Windsor) frozen at -20°C were analyzed at 169, 245, and 785 days after collection, to determine the effect of length of storage time on analytical results. Concentrations were compared by one-way ANOVA.

2.4.4. Dispersal Distance Studies

2.4.4.1. Sample Collection

The reliability placed on estimates of contamination of animals collected at a site depends upon confidence that these organisms emerge locally. Estimates of dispersal distance were made from light trap catches of representatives of six taxa common in the Lake Huron/Lake Erie connecting channel (Detroit and St. Clair Rivers). The taxa included the caddisflies,

Macrostemum zebratum (Hagen), Cheumatopsyche campyla Ross, Cheumatopsyche speciosa (Banks), Hydropsyche phalerata Hagen, and Hydropsyche hageni Banks (Trichoptera: Hydropsychidae) and the mayfly genus Hexagenia (H. limbata (Serville) and H. rigida McDunnough, (Ephemeroptera: Ephemeridae)).

Aquatic insects were collected on calm evenings along Rochester Township Concession Road 4 and along Rochester Townline on the south shore of Lake St Clair, Ontario, and along Essex County Road 10 near Amherstburg, Ontario, on the east bank of the Detroit River (Table 3). These locations were selected based on access to the lake or river and a minimum of potentially interfering street lights and/or residential lights. No other water bodies (lakes, rivers, or ditches) in the area sampled supported large populations of Hexagenia or Hydropsychidae. Eight identical light traps were set up, extending linearly away from the lake or river. Trap distances were 2-5, 78, 156, 312, 625, 1250, 2500 and 5000 m from the shore. Traps were operated simultaneously for 2 h following sunset. Air temperature, percent cloud cover, wind direction and estimates of wind velocity were recorded to assess the effect of meteorological conditions on dispersal abilities. Three replicate dispersal experiments were conducted at each location. Hexagenia and Hydropsychidae were collected at the Detroit River, and Hexagenia and Trichoptera were trapped at Lake St Clair. Time and direction of arrival were recorded for all Hexagenia individuals captured.

2.4.4.2. Sample Sorting

Hexagenia mayflies were separated from caddisflies and numbers of males and females were recorded. Due to the large numbers of caddisflies collected (30-65,000 animals per light trap), it was necessary to subsample large catches for species identification. All animals were identified in samples consisting $\leq$1000 animals, whereas in larger samples up to 1000 animals (6-8 g,

Table 3. Locations of dispersal distance study sites and sunset weather conditions.

Date	Location	Latitude (North)	Longitude (West)	Taxa Collected	Temp. (°C)	Wind velocity (km h^{-1})	Cloud cover (%)
17 July 1987	L. St. Clair	42°08'39"	83°06'25"	*Hexagenia*	20	SSE 0-5	0
23 July 1987	L. St. Clair	42°08'39"	83°06'25"	*Hexagenia*	24	SSW 0-5	60-80
29 July 1987	L. St. Clair	42°08'39"	83°06'25"	*Hexagenia*	22	SE 0-5	0-20
31 July 1987	Detroit R.	42°17'54"	82°43'05"	Hydropsychidae	22	E 0-10	60-70
11 Aug. 1987	Detroit R.	42°17'54"	82°43'05"	*Hexagenia* Hydropsychidae	19	NE 0-5	10-20
13 Aug. 1987	Detroit R.	42°17'54"	82°43'05"	*Hexagenia* Hydropsychidae	23	E 0-5	0-20
13 July 1988	L. St. Clair	42°09'05"	82°46'40"	*Hexagenia* *Hexagenia*	26	S 2-5	0
18 July 1988	L. St. Clair	42°09'05"	82°46'40"	*Hexagenia*	24	S 0-5	100
20 July 1988	L. St. Clair	42°09'05"	82°46'40"	*Hexagenia*	19	S 0-2	90

fresh wt.) were selected randomly and were identified to species. Subsamples were preserved in 70% ethanol and were sorted with the aid of a dissecting microscope. Five abundant species of hydropsychid caddisflies were identified. Only occasional representatives of other species were found. Reports of larval habitat preferences were obtained from the literature to confirm that the source of collected animals was the Detroit River (Table 4). Numbers of males and females of each species were also recorded.

2.4.4.3. Data Analysis

Data for Stations 3 (156 m) and 4 (312 m) were excluded from analyses due to unusually low numbers of animals captured compared to other locations. Stations 3 and 4 were located near bright street lights and/or were at the edge of densely vegetated areas that restricted visibility of traps.

Results of replicate studies were analyzed separately for each species. Only those replicates with >100 animals of a species were used for analyses. Thus, 2 replicates for Macrostemum and 5 replicates for Hexagenia were excluded from analyses, which resulted in 4 replicates of Hexagenia and a single replicate of Macrostemum dispersal data being analyzed. Three replicates were analyzed for all other species.

Several of the insect species exhibited synchronized emergence restricted to a relatively short period (2-3 weeks) in late June or July (Hexagenia, Hydropsyche phalerata, Macrostemum zebratum), while others emerged continuously throughout the summer (Cheumatopsyche campyla, Cheumatopsyche speciosa, Hydropsyche hageni). A difference of 10 days between replicate dispersal experiments resulted in broad variation in the total numbers of animals caught of species with synchronized emergence. Therefore, the numbers of animals caught per site were expressed as proportions for each species by dividing raw

Table 4. Species of Hydropsychidae caught in Detroit River light traps and larval habitat preferences.

Species	Larval habitat preference	Reference
Cheumatopsyche campyla Ross	Large rivers	Ross, 1944
Cheumatopsyche speciosa (Banks)	Large rivers	Ross, 1944
Hydropsyche phalerata Hagen	Large, warm rivers, (rapids)	Schuster and Etnier, 1978
Hydropsyche hageni Banks	Large, fast rivers, (rapids)	Ross, 1944
Macrostemum zebratum (Hagen)	Large rivers, (rapids)	Ross, 1944

numbers by the highest number of that species recorded per station on the evening of sampling. The relative proportions thus obtained were plotted against distance for each species, and least squares regression lines were fitted to each curve following appropriate transformation of the variables. Mean dispersal distances (m) were estimated by determining the area under each regression curve (animals x m) and dividing by the total number of animals (animals). Additionally, estimated distances travelled by 50 percent and by 10 percent of the organisms were calculated according to the regression models. These distances were used as radii of semicircles representing source areas of 50 and 90% of collected animals, respectively.

As a second test of adult insect dispersal and the utility of our traps for distinguishing local variation in environmental contaminant concentrations, we performed simultaneous trapping on the north and south banks of the Detroit River, downstream from Lake St. Clair. This study was conducted in collaboration with Dr. Mary Henry, (U.S. Fish and Wildlife Co-op, University of Minnesota). Sediments on the United States side of the Detroit River are heavily contaminated with PCBs and other organochlorine compounds, whereas sediments on the Canadian side are less heavily contaminated with PCBs but contain other compounds (OCS, HCB; Thornley and Hamdy 1984, Pugsley et al. 1985, UGLCCS 1988).

Sites were situated at a point where the Detroit River becomes separated into two channels by Belle Isle (Figure 2). Traps in Canada were situated at our East Windsor site (Figure 3). Traps on the U.S. side of the river were located at Memorial Park, Detroit (42°21'08"N, 82°59'09"W). Direct line distance between the two sites was 3.2 km. Two traps, 40 m apart were operated for 2 h following sunset at each site.

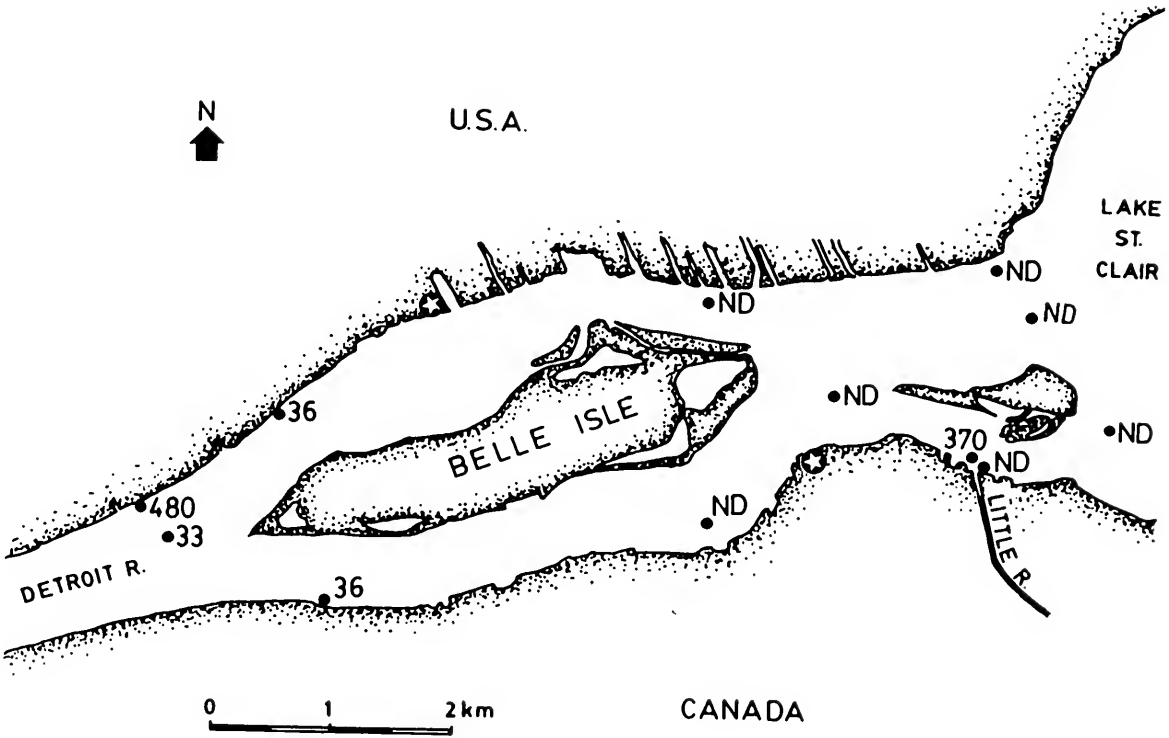

Figure 2. Locations of stations (indicated by stars) simultaneuosly sampled with light traps on the Canadian and U.S banks of the Detroit River. Numbers indicate sediment total PCB concentrations reported by Thornley and Hamdy (1984).

Three replicate samples of Hydropsychidae (mostly Cheumatopsyche) were analyzed from each of the four traps. Additionally, the large hydropsychid, Macrostemum zebratum was collected in sufficient numbers that 2 replicates from each site could be analyzed.

2.4.5. Seasonal Variation

Utility of trapping procedures depends upon the duration of season during which adequate numbers of animals can be collected. Trapping success depends upon local abundance, life history patterns and environmental conditions (temperature, humidity, wind direction and velocity). To determine the length of the practical trapping season, collections were made at four stations along the Detroit and St Clair rivers (near River Canard, Windsor, Port Lambton, and Sarnia; Figure 3, Table 2) at 7-day intervals throughout the emergence season of Year 1 of the study (15 May-20 Sept. 1987). Air temperature, wind velocity, and cloud cover were measured at sunset on each evening of sampling. Subsamples of catches were identified to the generic level. Stepwise multiple linear regression analysis was performed to identify which environmental variables in addition to calendar date and river were most important in influencing catches expressed as Log_e(sample fresh weights).

During Year 2 (1988), samples were collected from each of the above sites once during each of June, July, and August. Triplicate samples of Hydropsychidae or, in cases when low numbers of Hydropsychidae were collected, mixed Trichoptera, were analyzed for organic contaminants from all sites and months to assess seasonal variability in contaminant concentrations of animals.

2.4.6. Passive Light Trapping

Most of our collections were made during 2-h periods following sunset, with a person present to hand-collect any Hexagenia alighting in the vicinity

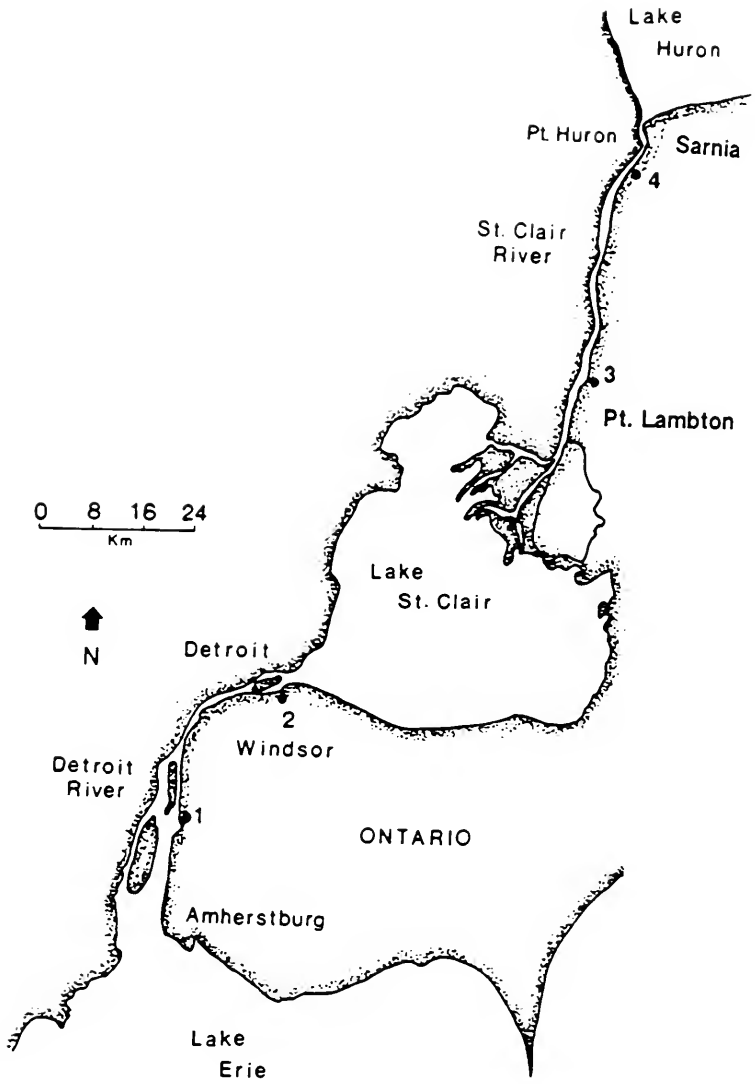

Figure 3. Locations of light trap sampling stations on the Detroit and St. Clair rivers.

of traps. However, constant monitoring is not necessary for the collection of Trichoptera, since these animals entered the traps readily. To determine whether more extended collection either generates a different relative composition of trichopteran taxa or attracts insects with different levels of contaminants, we conducted studies at the Detroit River in August and September 1988, and in July 1989. A total of four traps were set up in a series, at 20-m intervals, and the lights were switched on simultaneously. Traps 1 and 3 were monitored for the standard 2-h period following sunset, after which time animals were frozen and processed according to our standard protocols. Traps 2 and 4 were allowed to operate unattended overnight. These traps were emptied and the contents processed the following morning. All animals were treated in a manner identical to our standard protocol. Three replicate samples were analyzed from each type of trap from our 1989 collection. Owing to low air temperatures during collections in 1988, insufficient material was collected for GC analysis on previous occasions.

2.4.7. Interfamilial Comparisons

Since larvae in different families of Trichoptera feed differently, one may expect differences in exposure to organochlorine contaminants among animals with different feeding habits. Hydropsychid larvae are filter-feeders, and build nets of various mesh sizes to trap suspended food particles transported by the river currents. Leptocerid larvae employ various feeding methods, ranging from detritus feeding and herbivory to predation. Based on feeding type it is possible to make predictions as to the degree of exposure of a given species of aquatic insect to contaminants. Since organochlorine compounds tend to adsorb to suspended sediment (UGLCCS 1988) or partition into the lipid phase of animals either by direct contact or through feeding, filter-feeders and predators can be expected to be more contaminated than

herbivores and detritivores. To test this hypothesis we analyzed triplicate samples of caddisflies of different families and genera collected on the same evening from the same station. We assumed that the animals of different taxa originated in the same general area, though it is understood that microhabitat preferences may vary among taxa. Contaminant concentrations in St. Clair River Leptoceridae and Hydropsychidae, and Niagara River Hydropsychidae and Psychomyiidae were compared.

2.4.8. Comparison of Contaminant Concentrations of Animals Differing in Lipid Content

A standard procedure in the assessment of organochlorine contaminant concentration for many aquatic organisms now consists of "correcting" for the lipid fraction. Because organochlorine compounds are lipid soluble, the lipid fraction of an animal's tissue harbours the majority of chemical (Nimmo et al. 1970). Since different tissues contain varying amounts of lipid, it is customary to report contaminant concentrations of tissue analyses that constitute only a portion of a large organism on a contaminant concentration per unit lipid basis rather than per unit tissue. Other workers have argued that such lipophilicity applies not only to tissues within individuals, but among individuals with differing lipid composition (Clark et al. 1988). This has led to a tendency to explain species-to-species variation in contaminant concentrations in terms of varying lipid proportion. This assumption is difficult to test because differences in lipid content among individuals usually reflect different feeding history and/or microhabitat use - factors that potentially provide for differential exposure to and uptake of contaminants. Coincidentally, expressing contaminant concentrations on a per unit lipid basis may obscure the influence of these potential confounding factors.

Our collections of male and female Hexagenia and Macrostemum adults permitted us to test the assumption that contaminant concentration depends entirely on the amount of lipid stored in an organism's body. We have consistently measured significantly higher lipid contents in males of Hexagenia and Macrostemum than in females (Hexagenia, male: 21.83±0.561%, female: 18.49±0.145%, $p<0.005$; Macrostemum, male: 16.02±0.274%, female: 15.00±0.227%, $p<0.05$, one-way ANOVA). However, male and female larvae occupy identical microhabitats and presumably come into contact with equivalent quantities of organic contaminants. If contaminant concentration is entirely lipid-controlled, then there should be no significant difference in the concentration of contaminants between females and males on a per unit lipid basis, whereas concentration for males on a per unit dry weight basis should be significantly higher than that of females. In contrast, if total burden is not lipid-dependent, then body concentration expressed on a per unit dry weight basis should be equivalent between sexes.

We collected male and female Hexagenia subimagoes from the Detroit River at our East Windsor sampling station (Figure 3) on 8 July 1989, and Macrostemum at Amherstburg, Ontario, on 10 July, 1989. During our previous collections, we observed considerable loss of eggs in samples of imagoes of Hexagenia. Subimagoes with full egg loads were used to minimize the possibility of egg loss which, due to their high lipid content, contain high concentrations of contaminants. No loss of eggs was observed in samples of Trichoptera. We assumed that all females collected were gravid. Three replicate samples of each sex of each species were analyzed by GC.

In addition, since lipid contents of all our samples were determined, and a range of approximately 18 percentage points (6-24% lipid per sample, by dry weight) was found in lipid content in our various samples, we used linear

regression to examine the relationship between lipid content (percent of dry wt.) and total quantified contaminants (ug kg^{-1} dry weight) in all samples used for site comparisons (47 samples) during years 1 and 2 of our study.

2.4.9. Validation

2.4.9.1. Sample Collection

If sampling protocols are to be of general applicability, their successful use must be demonstrated over a range of geographic regions and/or ecological conditions. Following development of efficient procedures for collecting locally, collections were made at two other regions in the Great Lakes Basin using standard light traps and protocols. We conducted surveys of adult insects at five sites on the Niagara River (5-6 July 1988) and at four locations on the St. Marys River (28-30 June and 15-17 Aug. 1988; Table 5). Three replicate samples of Hydropsychidae (mostly Cheumatopsyche) were analyzed from the upstream three of five sites (Erie Beach, Fort Erie and Black Creek) at the Niagara River. In addition, we analyzed three replicate samples of Ceraclea (Leptoceridae) from the two downstream sites (Niagara Gorge and Lake Ontario) and two replicates of Psychomyiidae from one site (Black Creek). Due to inclement weather, only Trichoptera were collected in sufficient quantities for GC analysis at the sites on the St. Marys River, and only two replicates could be analyzed from two of the sites.

Results of contaminant analyses of collected samples were compared to reports of sediment contamination in the literature, as well as to results of contaminant analyses of samples collected at the Detroit and St. Clair rivers.

2.4.9.2. Data Analyses

Principal component analysis (PCA) was used to identify groups of associated compounds, using contaminant concentrations in caddisfly adults

Table 5. Locations of stations sampled during the validation study, and sunset weather conditions, (NR = Niagara River, SMR = St. Marys River).

Stn.	River	Designation	Latitude (North)	Longitude (West)	Date	Temp. (^{o}C)	Wind km h^{-1})
1	NR	Erie Beach	42°53'05"	78°55'47"	5 July	28	calm
2	NR	Ft. Erie Bridge	42°54'42"	78°54'33"	5 July	28	calm
3	NR	Black Creek	42°59'43"	79°01'40"	5 July	28	calm
4	NR	Niagara Gorge	43°07'15"	79°04'25"	6 July	27	calm
5	NR	L. Ontario	43°15'34"	79°04'20"	6 July	27	calm
1	SMR	L. Superior	46°30'51"	84°54'33"	28 June	16	S 30
					30 June	13	W 0-5
					15 August	18	calm
2a	SMR	Bell's Point	46°32'15"	84°13'10"	28 June	16	calm
2b	SMR	Reserve	46°32'02"	84°81'02"	15 August	18	calm
3	SMR	Pine Island	46°19'09"	83°47'25"	29 June	13	W 30
					15 August	18	calm
4	SMR	French Island	46°17'24"	83°47'25"	29 June	13	W 30
					15 August	18	calm

collected at sampling stations on the Detroit, St. Clair, Niagara, and St. Marys rivers. Compounds with high variation among replicates (coefficient of variation >50%, n=3) were excluded from the analysis, since such variability is more likely the result of procedural errors rather than a reflection of environmental heterogeneity. To simplify presentation of our results, we selected representative compounds (Table 6), based on the PCA. Five PCB congeners (one of each with 4, 5, 6, 7, and 8 chlorine atoms per molecule), dieldrin and OCS were selected. These representative compounds also were used for presenting data on small-scale spatial variation in contaminant level (opposite banks of the Detroit River) and seasonal variation in contaminant concentrations. However, complete data on all quantified compounds are presented in Appendix 2.

To explore the relationships between contaminant concentrations of animals captured from the 4 connecting channels, principal component (PC) scores (3 PC factors, see below) were used as data for cluster analysis (hierarchical agglomerative clustering of Euclidean distances, Ward's method) of all samples collected at the Detroit, St. Clair, Niagara, and St. Marys rivers. One-way ANOVA followed by Student-Newman-Keuls test was used to compare mean PC scores of samples falling into different clusters.

3. RESULTS

3.1. Sample Collection

3.1.1. Trap Operation and Efficiency

The light traps collected large numbers (up to 65,000 (500g)) of aquatic insects. Setup and operation of the traps was simple, requiring no special skills.

Table 6. Correlation between concentration of organochlorine contaminants and principal components for samples of caddisflies collected from Great Lakes connecting channels. PCB numbering follows Ballschmiter and Zell (1980).

Compounds (No. of chlorine atoms)	PC-1	PC-2	PC-3
* PCB 201 (8)	**0.956**	0.083	-0.077
PCB 141 (6)	**0.944**	0.233	-0.117
* PCB 180 (7)	**0.937**	0.254	-0.100
PCB 182 (7)	**0.929**	0.28	-0.104
PCB 203 (8)	**0.915**	0.053	-0.058
PCB 170 (7)	**0.911**	0.245	-0.018
PCB 194 (8)	**0.902**	0.146	-0.049
PCB 151 (6)	**0.891**	0.275	-0.070
* PCB 138 (6)	**0.886**	0.312	-0.084
* PCB 101 (5)	**0.859**	0.394	-0.113
PCB 153 (6)	**0.854**	0.391	-0.115
PCB 110 (5)	**0.777**	0.435	-0.038
* PCB 52 (4)	**0.773**	0.482	-0.080
PCB 66 (4)	**0.770**	0.445	-0.036
PCB 118 (5)	**0.767**	0.273	-0.022
PCB 87 (5)	**0.755**	0.523	-0.049
PCB 70 (4)	**0.746**	0.357	0.009
DDE	**0.710**	0.387	-0.088
PCB 97 (5)	**0.680**	0.590	-0.055
PCB 44 (4)	**0.557**	0.371	0.341
HEPTACHLOR EPOXIDE	0.258	**0.893**	-0.026
* DIELDRIN	0.286	**0.881**	-0.033
α-BHC	0.100	**0.630**	0.129
* OCS	-0.124	0.086	**0.957**
HCB	0.032	0.321	**0.839**
QCB	0.382	0.151	**0.540**

* Representative compounds

Single collections required an average of 2 kg of dry ice. Up to 3 kg were needed on warm, humid nights (26°C, 80-90% relative humidity). Since the traps were not air-tight, greater amounts of dry ice were needed on windy nights. The CO_2 sublimating from the dry ice quickly killed the insects entering the trap and cooled the sample, minimizing deterioration. Water condensation on the funnel and the vanes was noticeable only on especially humid nights, usually during the second hour of collection, by which time general nocturnal insect activity had considerably declined.

Under ideal collecting conditions, the trap collected large numbers of insects without dry ice, provided that the reservoir was emptied at 15 minute intervals to prevent the animals from escaping.

Ideal nights for collecting large numbers of insects were warm, humid, and calm. Very few organisms were caught at temperatures below 18°C. Catches were usually reduced by the presence of other light sources, such as bright street lights, within 50 m of the light trap. Largest catches at all sampling stations were recorded at wind velocities <10 km h^{-1}. At wind speeds >15 km h^{-1} catches were greatly reduced, often to fewer than 20 insects over the two-hour sampling period. The light trap was susceptible to being blown over at wind velocities >20 km h^{-1}.

In general, mayflies were more strongly affected by wind than were caddisflies. At wind velocities >5 km h^{-1} mayflies usually arrived with the wind. Below this wind velocity direction of arrival was independent of wind direction. Although detailed data were not collected, relative humidity also seemed to influence catches; larger samples were collected on more humid nights.

3.1.2. Taxonomic Composition of Samples

Caddisflies and mayflies comprised the bulk (>80% by fresh weight) of the samples collected at all sites. Most of the Trichoptera captured belonged to the families Hydropsychidae and Leptoceridae. Details of the taxonomic composition of Trichoptera captured at Detroit R. sites in 1988 are listed in Appendix 4. Hexagenia was the numerically dominant mayfly at Stations 2,3 and 4, on the Detroit and St. Clair rivers, but was only caught in large enough numbers for contaminant analysis in late June/early July, during its peak emergence period. Few or no mayflies were caught at Station 1 (River Canard) throughout the sampling season in 1987.

There were noticeable differences in diversity among weekly samples obtained at the different stations. The River Canard site was located near marshland. Catches at this station contained considerably more representatives of other insect orders, both aquatic and terrestrial, than those at the other stations. All other sampling stations were situated near rocky shores or breakwalls. Samples collected at those locations were dominated by Trichoptera and required less sorting time than those from the River Canard station.

Numbers of Caenis latipennis (Ephemeroptera: Caenidae) caught at the four stations were variable and depended on wind velocity and direction. This tiny, short-lived mayfly was found to be occasionally very abundant, especially at sampling stations located near marshes. However, the large numbers required for contaminant analysis (1000-2000/replicate), the amount of sorting time required to separate Caenis from other animals, and its weather-dependent availability may reduce the usefulness of Caenis in contaminant monitoring.

Abundances of other taxa (Chironomidae (Diptera), Coleoptera, Megaloptera) were low and sporadic at most sampling stations. Aquatic

Coleoptera were occasionally numerous at the River Canard sampling station.

3.1.3. Collection of Emerging Adults

3.1.3.1. Scoop Netting

Many decomposing imagoes were observed on the water surface, but less than a dozen living subimagoes were captured on either occasion when sampling from a boat was attempted. Although some emergence of Hexagenia subimagoes appears to occur in late morning (J.J.H. Ciborowski pers. obs.) on Lake St. Clair, lake conditions would seldom be calm enough at this time of day to permit regular collection with any degree of certainty. Visibility is minimal during the 2 h following sunset, at which time most Hexagenia emergence occurs (Hunt 1953). Thus, simple scoop netting does not appear to be a viable method of capturing locally emerging individuals on a regular basis.

3.1.3.2. Submersed Traps for Larvae

We captured no aquatic insects during a study on 22 June 1988, and 9 July 1989 using submersed traps. A single, large Hexagenia larva entered the trap on 4 July 1988. These data suggest that capture of nymphs by this method is unlikely to yield adequate material for contaminant analysis.

3.1.3.3. Boat-mounted Light Traps

Our traps attracted several hundred Hexagenia subimagoes and imagoes on each sampling occasion, as well as numerous hydropsychid caddisflies. We presumed that subimagoes had recently emerged from the lake in the vicinity of the trap. Hexagenia adults must alight on a substrate in order to shed their subimaginal cuticle, suggesting that trapped imagoes had probably emerged away from the immediate vicinity of the light traps. Thus, subimagoes appear better suited than imagoes as indicators of local sediment contamination.

3.1.4. Collection of Bottom-dwelling Larvae

Ekman and Peterson grab collections of benthic larvae in Lake St. Clair yielded insufficient material for GC analysis on all occasions (<1 g larvae (wet weight) in 20 samples).

Larvae of Detroit River Hydropsychidae failed to colonize the aluminum screening in large numbers, and only small (3-6 mm) larvae were found attached to the screening. Since larvae of Hydropsychidae build retreats on the substrate and are relatively sessile, this sampling technique would be successful only on a long term (1 yr.) basis, or in smaller, shallow rivers, where colonization processes are more rapid.

We were most successful at collecting large numbers (>300) of hydropsychid larvae in the Detroit River by manually removing animals from the surface of submerged rocks in wave-washed zones of the riverbank. Animals collected were variable in size (0.6-1.4 cm), and many pupae were seen. Since the species that we collected in greatest numbers (Hydropsyche alterans) appears to be relatively synchronized in its emergence (mid to late July), sampling for late instar larvae should be timed appropriately.

3.2. Contaminant Analyses — Overall Analysis

Detailed results of contaminant analyses are listed in Appendix 2. Contaminant analyses detected a minimum of 25 of the 30 contaminants studied in all samples from reference areas. Results of cluster analysis of all stations sampled in 1987-1988 are presented in Fig. 4.

Cluster analysis of animals collected from all stations sampled in 1987-1988 distinguished 5 groups of samples based on contaminant concentrations. Some samples were grouped according to geographic source area, usually river (Cluster IV) or connecting channel (Cluster III). Other clusters contained

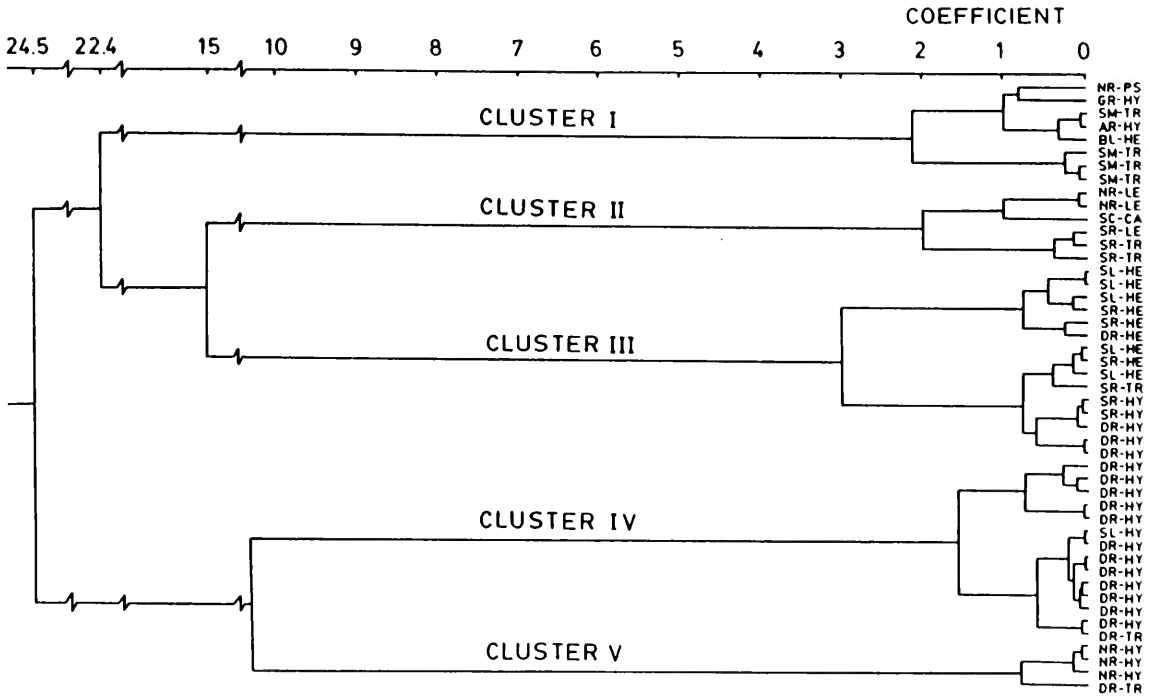

Figure 4. Dendrogram of cluster analysis of samples collected at all stations in 1987 and 1988 (NR: Niagara River, GR: Gull River, SM: St. Marys River, AR: Ausable River, BL: Balsam Lake, SC: Scugog Lake, SR: St. Clair River, SL: Lake St. Clair, DR: Detroit River, PS: Psychomiidae, HY: Hydropsychidae, TR: Trichoptera, HE: Hexagenia, CA: Caenis, LE: Leptoceridae).

samples with differing geographic sources (Clusters I, II, and V), although in the case of Cluster V, 75 % of samples originated in the Niagara River. Reference samples were grouped in Cluster I, regardless of sampling location or taxonomic composition, implying the occurrence of similar amounts and types of OC contaminants in those samples. Cluster II samples (Niagara River Ceraclea, Lake Scugog Caenis, and St. Clair River Trichoptera) formed a unique group due to low concentrations of pesticides.

Significant differences were found among mean PC-scores of clusters for each of the 3 PCs (one-way ANOVA, $p<0.001$). Results of Student-Newman-Keuls tests comparing mean PC scores for each PC are indicated on Fig. 5.

Samples from reference areas (Cluster I) had the lowest mean values of PC-1 and PC-2, indicating low concentrations of PCBs, DDE, and "other" OC compounds (QCB, HCB, OCS) in these samples. Concentrations of pesticides (PC-3) in these samples were not significantly different from those in samples from the Detroit River and Lake St. Clair (Clusters III and IV). Highest PCB (PC-1) concentrations were recorded in samples of Detroit River Hydropsychidae (Cluster IV), which correspond to reports of high PCB concentrations in Detroit River sediments (UGLCCS 1988). Levels of "other" OC compounds (PC-2) were greatest in Lake St. Clair and St. Clair River Hexagenia, and upper Detroit and St. Clair River Trichoptera (Cluster III), while levels were also elevated in all other samples of aquatic insects from the Detroit and St. Clair rivers (Clusters II and IV). These data also correspond to reported local sediment contaminant levels (UGLCCS 1988). Highest levels of OC pesticides (PC-3) were observed in Cluster V, consisting mostly of Niagara River Hydropsychidae. Concentrations of pesticides were also elevated in Clusters I, III, and IV.

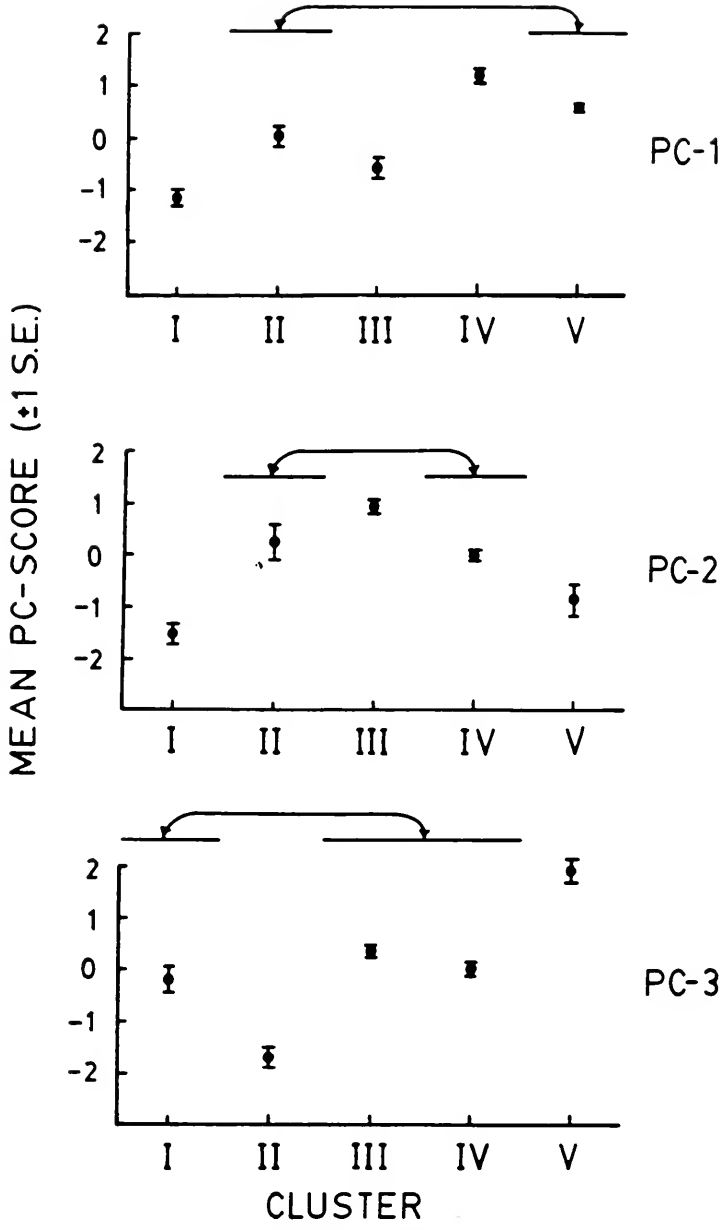

Figure 5. Mean (+1 S.E., n=3) principal component scores of groups distinguished by cluster analysis of all 1987 and 1988 samples. Means not significantly different from one another are connected by horizontal bars or double-ended arrows ($p>0.05$, Student-Newman-Keuls test, n=3).

3.3. Specific Studies

3.3.1. Detection Limits in Uncontaminated Areas

Collection at Horseshoe Dam provided a 285 g sample of Hydropsyche. Our Balsam Lake sample was dominated by Hexagenia (70 g), while only Caenis was collected at Lake Scugog. Biomass collected in early August in the same area was much reduced. The sample collected at the Ausable River contained predominantly Hydropsychidae.

Concentrations of the representative contaminants in Hexagenia collected at 3 sites along the Detroit and St. Clair rivers were compared to those at Balsam Lake (Fig. 6). Significantly higher levels of contaminants were detected in samples from the Detroit and St. Clair rivers (one-way ANOVA, $p<0.05$). Exceptions were dieldrin at Station 3 (Sombra, St. Clair River) and PCB 66 at Station 4 (Sarnia, St. Clair River), concentrations of which were not significantly different from those at Balsam Lake. In both cases, large variation among replicates reduced the power of statistical tests. Contaminant concentrations were significantly higher in Hydropsychidae at Station 1 (Detroit River) than at central Ontario sites (Ausable River and Gull River, Fig. 7. Pesticide concentrations were elevated in samples from the latter sites when compared to levels of other contaminants. The higher concentrations most likely reflect local agricultural use.

3.3.2. Minimum Sample Size

Results of analyses performed to determine minimum sample size are presented in Fig. 8. Median coefficients of variation calculated from contaminant concentrations of 29 compounds in replicate samples of Hexagenia from Station 2 (East Windsor, Detroit River) declined to an asymptote (20%) at 0.38 g dry weight (25 animals, Fig. 8A). The proportion of nondetectable compounds also declined to approximately 20% at the same weight. Based on

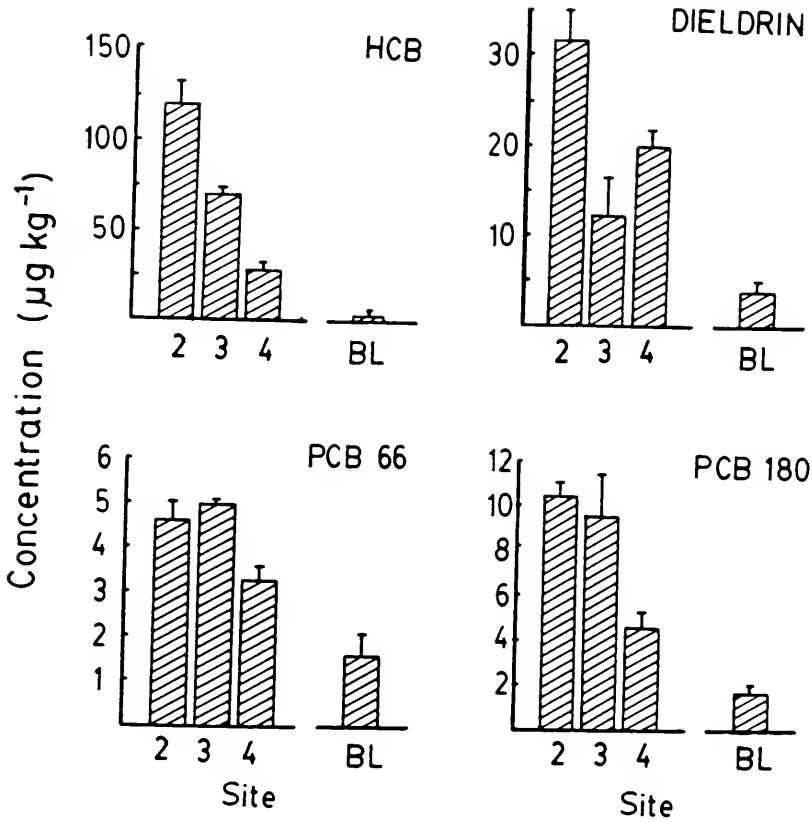

Figure 6. Comparison of mean (±1 S.E., n=3) contaminant concentrations in Hexagenia at three Detroit and St. Clair River sites to that in the Balsam Lake (BL) sample. Numbering of sites corresponds to that in Figure 3.

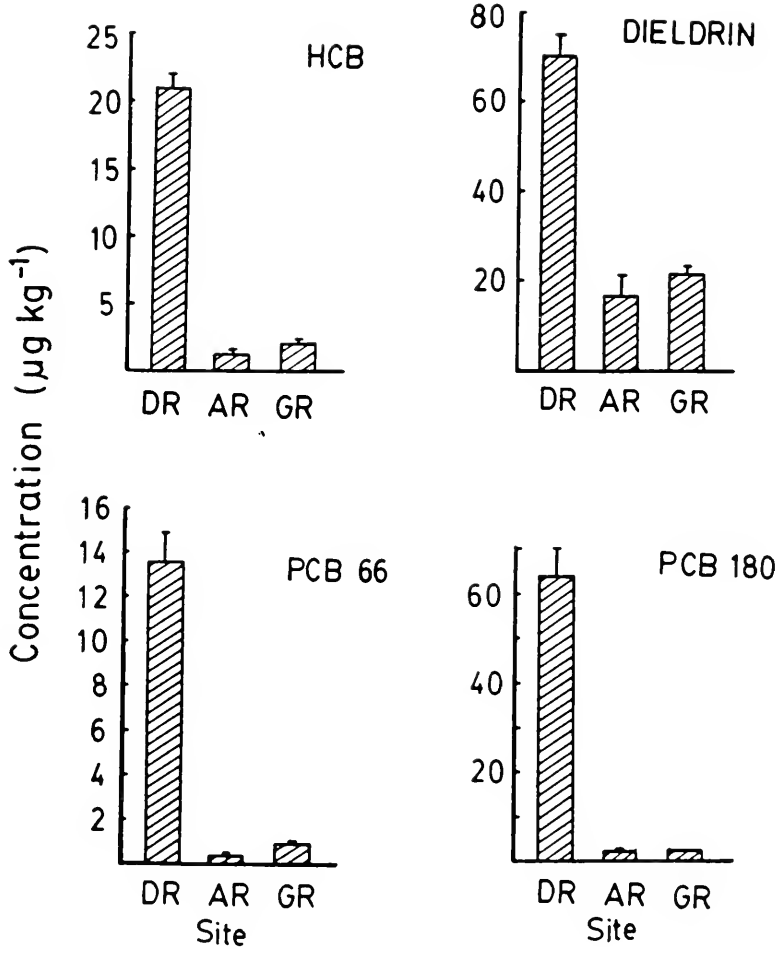

Figure 7. Comparison of mean (±1 S.E., n=3) contaminant concentrations in Trichoptera from the Detroit River and two reference sites (DR: Detroit River, AR: Ausable River, GR: Gull River).

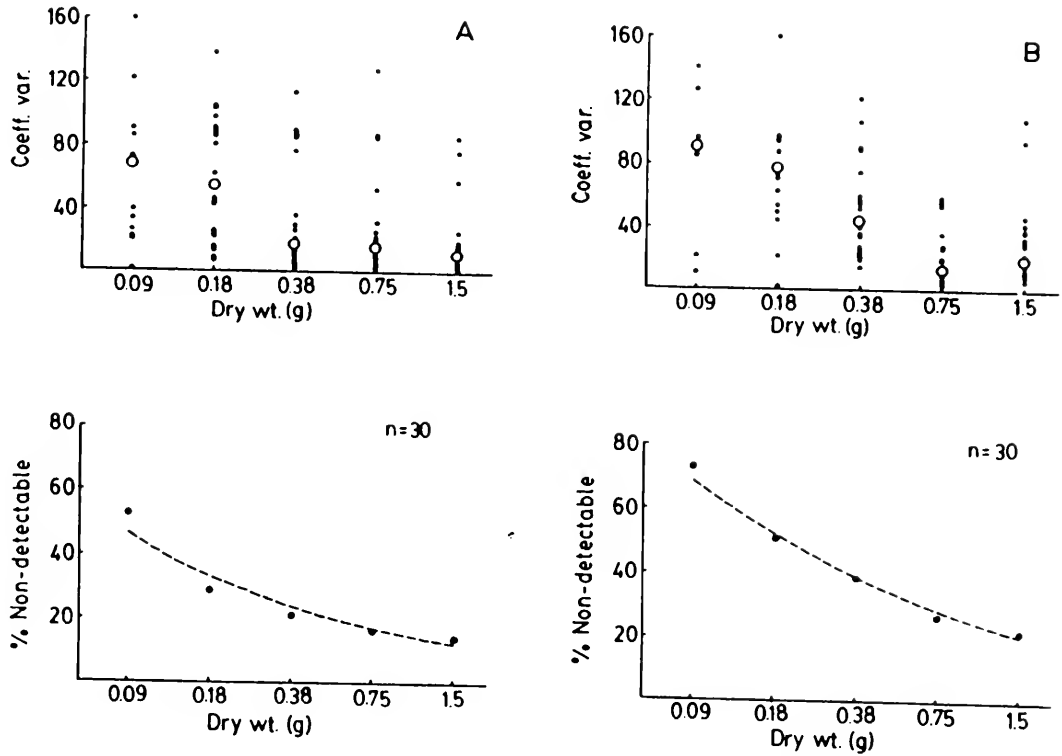

Figure 8. Coefficients of variation and percent non-detectable compounds plotted against sample dry weight for (A) Hexagenia at Site 2, and (B) Trichoptera at Horseshoe Dam (central Ontario). Median values are represented by large open circles.

these results, a minimum sample dry weight of 0.38 g yields acceptable variation in areas of known high organochlorine contamination. Similar analyses of samples of Hydropsyche from the Gull River suggest that a minimum sample dry weight of 0.75 g (170 animals) is appropriate (Fig. 8B). The larger biomass estimate required reflects the lower concentrations of contaminants in these samples. Use of the larger sample size is advised when analyzing samples from previously unstudied areas.

3.3.3. Storage Time and Temperature

Storage temperature did not significantly influence analytical results (one-way ANOVA, $p<0.05$). No contaminant loss was noted in animals in either of the fractions of samples split and stored at -20 and -70°C for 169 days, and results of GC analysis were identical. An additional storage period of 60 days resulted in no significant differences in analytical results (one-way ANOVA, $p>0.5$, Table 7). However, 785 days of storage resulted in a significant decline (30%) in total contaminant concentrations of samples analyzed (one-way ANOVA, $p<0.05$).

3.3.4. Boat-Mounted Light Traps

Independent contaminant analyses of Hexagenia subimagoes and imagoes suggest that the different developmental stages collected originated in different geographic areas. Concentrations of "other" organochlorine compounds in imagoes were 50% lower than those in subimagoes, while pesticides were 40% higher, and PCBs were 66% higher in imagoes (Table 8). Lower concentrations of PC-2 compounds could possibly be attributed to selective removal of these chemicals during molting. However, the large increases in PCB and pesticide concentrations in imagoes following the final molt imply either significant uptake by imagoes, or a different source population. Since Hexagenia imagoes are short-lived and do not feed, contaminant uptake is

Table 7. Mean (±1 S.E.) concentrations of representative contaminants in insects stored at different temperatures and for various time periods.

Taxon (Storage temp. °C)	No. days of storage	Contaminant (μg kg^{-1} dry wt.)					
		PCB 52	PCB 101	PCB 138	PCB 180	Dieldrin	OCS
Hexagenia (-20)	169	6.73 (0.128)	12.99 (0.983)	19.30 (0.919)	10.77 (0.544)	31.42 (3.294)	18.81 (1.830)
Hexagenia (-20)	245	7.03 (0.497)	13.053 (0.688)	18.19 (1.344)	10.438 (0.893)	28.06 (1.558)	19.83 (0.692)
Hexagenia (-70)	169	6.758 (0.566)	13.49 (0.879)	19.57 (2.124)	10.05 (0.765)	28.52 (5.117)	17.41 (1.382)
Hexagenia (-20)	785	6.11 (0.214)	11.51 (0.664)	15.26 (1.108)	8.96 (0.769)	28.05 (0.788)	14.624 (0.218)
Hydropsyche (-20)	172	1.32 (0.155)	2.69 (0.512)	5.75 (0.627)	2.43 (0.030)	22.40 (1.252)	0.26 (0.120)
Hydropsyche (-70)	173	1.20 (0.156)	3.28 (0.275)	5.03 (0.502)	3.22 (0.588)	18.01 (2.076)	0.13 (0.111)

Table 8. Mean (±1 S.E.) concentrations of representative contaminants in Hexagenia imagoes and subimagoes caught in boat-mounted light traps.

Developmental stage	% Lipid (dry wt.)	Contaminant ($\mu g\ kg^{-1}$ dry wt.)						
		PCB 52	PCB 101	PCB 138	PCB 180	PCB 201	Dieldrin	OCS
subimago	16.45 (1.445)	9.47 (2.518)	8.02 (0.799)	9.38 (0.762)	4.84 (0.280)	0 --	17.06 (1.063)	8.71 (0.673)
imago	16.84 (0.440)	6.78 (0.756)	12.43 (1.009)	17.22 (2.435)	13.37 (1.865)	1.81 (0.210)	15.84 (0.186)	5.91 (1.651)

unlikely. Although some of the imagoes collected were probably local emergents, dispersal by a large proportion of collected animals from a source population in the upper Detroit River, which contains sediments moderately contaminated by PCBs (Thornley and Hamdy 1984), is the more likely explanation. Burdens of PCBs in Lake St. Clair imagoes were similar to those of upper Detroit River imagoes, while pesticide concentrations were lower than those of upper Detroit River imagoes. The subimagoes collected were probably local emergents, since we sampled at 9-11 p.m., a period of peak emergence of Hexagenia (Hunt 1953), and weather conditions were suitable for emergence. Therefore, active or wind-induced dispersal by imagoes most likely accounts for our discrepant findings.

3.3.5. Comparison of Contaminant Burdens of Adults and Larvae

Contaminant burdens (total extracted contaminants) of adults of Hydropsyche alterans were 5-6 times higher than those of larvae (Table 9). This result conforms to expectations, since most of the larvae collected were relatively small (2nd to 3rd instar), having developed from eggs laid in early summer.

3.3.6. Dispersal Distance Studies

Meteorological conditions were similar during all dispersal studies (Table 3), with a mean ($\pm$1 S.E.) temperature of $22.1 \pm 0.81^{\circ}C$ and wind velocities below 10 kmh^{-1}. Estimated cloud cover was variable (0-100%). The effect of cloud cover on adult insect activity is relatively minor (section 3.3.7.1). The high consistency of weather conditions during all dispersal studies did not permit us to study the effect of variation in meteorological conditions on insect dispersal.

Table 9. Mean (±1 S.E.) concentrations of representative contaminants in adult and larval *Hydropsyche alterans*.

Developmental stage	% Lipid (dry wt.)	Contaminant ($\mu g\ kg^{-1}$ dry wt.)						
		PCB 52	PCB 101	PCB 138	PCB 180	PCB 201	Dieldrin	OCS
larva	10.20	41.20	55.81	85.09	21.25	4.75	7.60	12.03
	(0.707)	(1.238)	(5.247)	(14.359)	(3.950)	(1.501)	(0.197)	(0.090)
adult	14.60	129.20	355.34	622.02	135.71	17.469	28.76	46.72
	(0.263)	(22.929)	(83.239)	(176.095)	(29.179)	(3.656)	(4.150)	(6.413)

Three of the caddisfly species studied exhibited inland maxima when means of standardized proportions of animals collected (n=3) were plotted against distance from water (Fig. 9). Hydropsyche hageni, H. phalerata and Macrostemum zebratum were collected in greatest numbers at some distance inland, while Cheumatopsyche campyla and C. speciosa were most abundant at the riverbank. Modal dispersal distances were consistent among replicates for all caddisfly species. Both of the above patterns were seen in numbers of Hexagenia, and replicates were grouped accordingly for the plots (Fig. 9). Of the total number of animals caught, only 1.63 (±0.623) per cent were captured at the 5000 m station during all studies, indicating that the trap distances chosen were appropriate for the dispersal abilities of the animals studied.

Relative species composition of Detroit River hydropsychid caddisflies varied considerably with increasing distance from the riverbank to 1000 m inland (Fig. 10), but was relatively constant from 1000 m to 5000 m. Cheumatopsyche campyla was the numerically dominant caddisfly during all dispersal studies conducted along the Detroit River.

Mean dispersal distance and distance travelled by 50 and 10% of animals are listed in Table 10 along with estimates of the area of recruitment for each species of caddisfly collected. There were significant differences among species in mean distances travelled (one-way ANOVA, $p<0.05$). Generally, Cheumatopsyche dispersed shorter distances than Hydropsyche species (Figure 11). However, due to the high variation among replicates few distinct differences could be detected among mean distances travelled by the different species (Duncan's multiple range a posteriori test, $p<0.05$).

Our source area estimates (Table 10) for the insects captured suggest that our samples represent animals recruited from an area of up to 25 km^2.

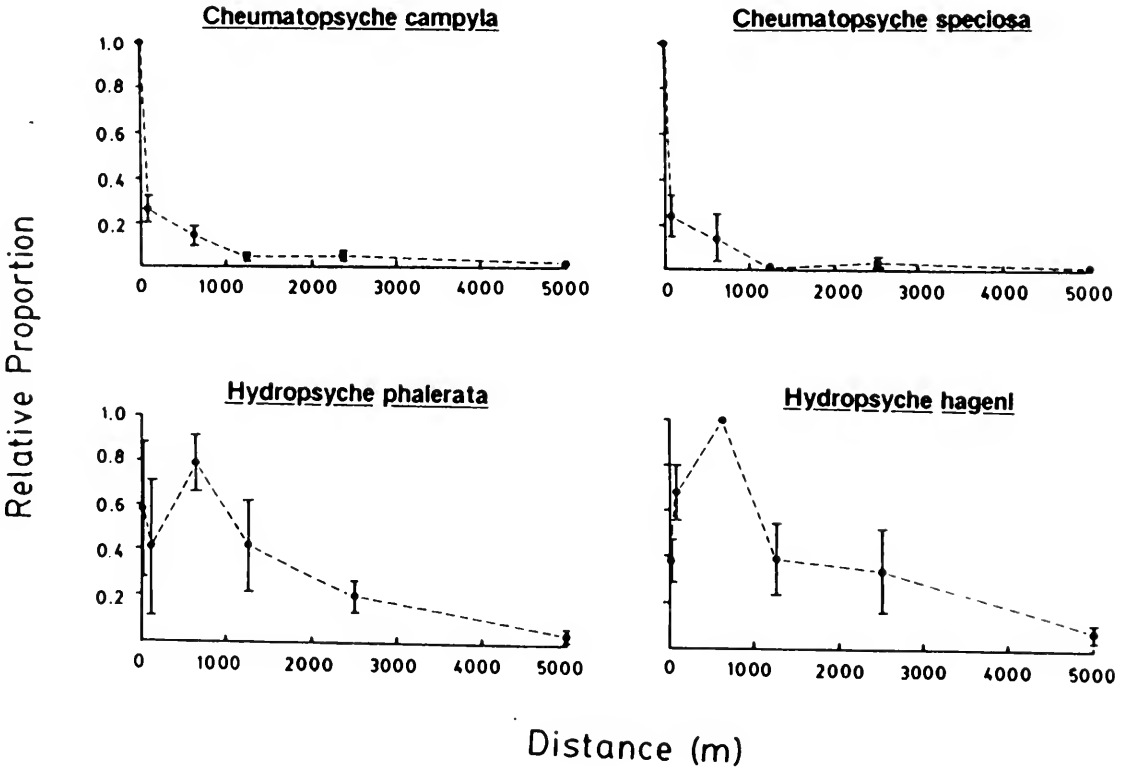

Figure 9. Relationship between catch of adult insects in light traps and distance inland from waterbody. Each curve represents collection on three nights, except where otherwise indicated.

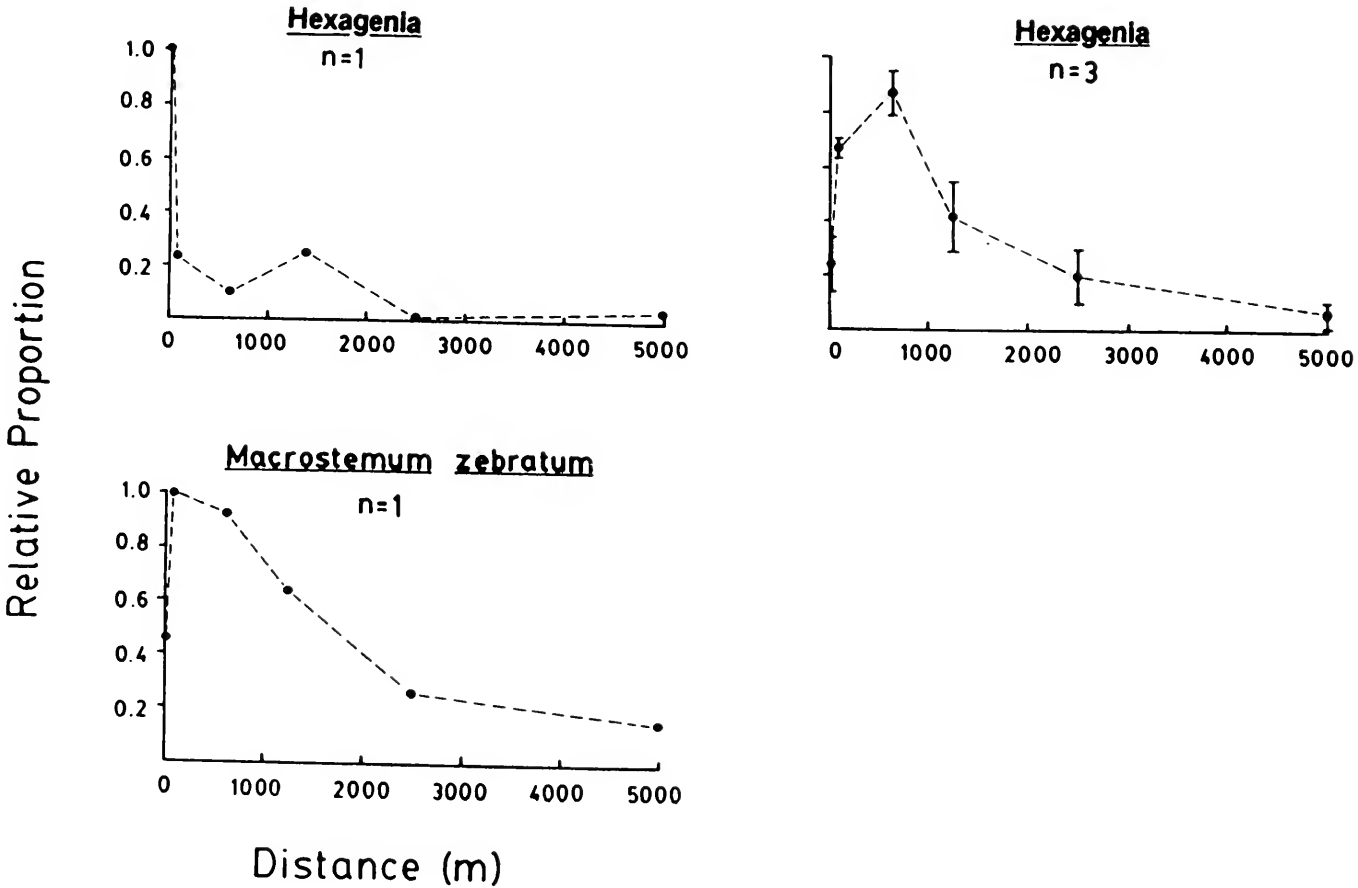

Figure 9. (Continued)

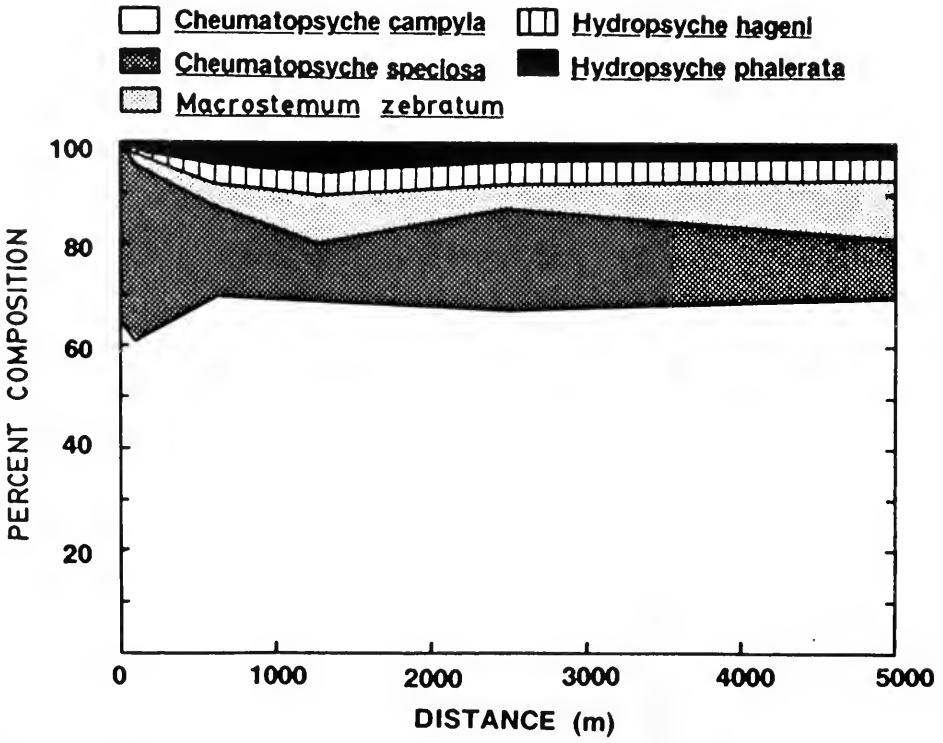

Figure 10. Relationship between species composition of Detroit River samples of Hydropsychidae and distance from water body.

Table 10. Dispersal parameters of aquatic insects collected during the dispersal studies.

Species	Mean distance (m)	Modal distance (m)	D_{50} (m)	D_{90} (m)	A_{50} (km^2)	A_{90} (km^2)
Cheumatopsyche campyla	670.3 (142.3)	0	502.0 (106.3)	1573.2 (334.2)	0.43 (0.19)	4.24 (1.81)
Cheumatopsyche speciosa	650.3 (227.1)	0	487.7 (169.6)	1527.0 (533.7)	0.47 (0.30)	4.56 (2.96)
Hydropsyche phalerata	1685.7 (329.2)	625	1470.4 (348.1)	3386.4 (572.2)	3.78 (1.65)	19.40 (5.95)
Hydropsyche hageni	1499.1 (267.4)	625	1180.3 (338.7)	3261.7 (337.4)	2.55 (1.39)	17.07 (3.63)
Macrostemum zebratum	1845.5 --	78	1557.6 --	3984.4 --	3.81 --	24.93 --
Hexagenia	1213.3 (192.5)	625	900.4 (199.5)	2778.6 (371.2)	1.46 (0.66)	12.78 (3.50)

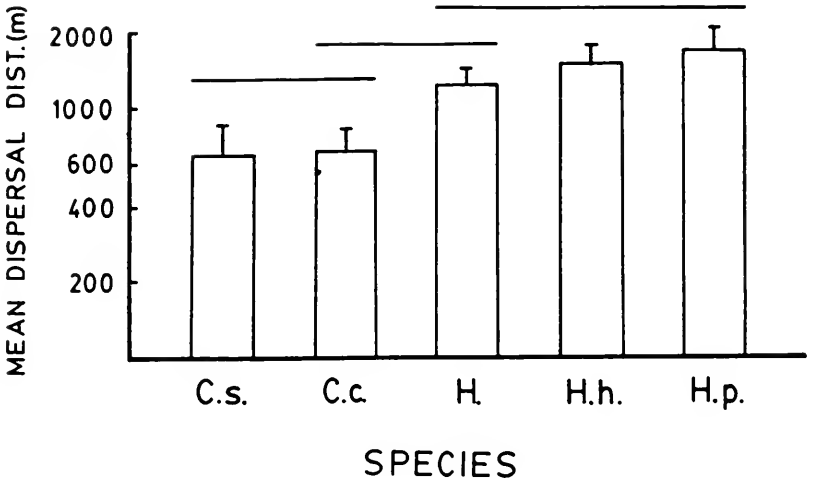

Figure 11. Comparison of mean (±1 S.E., n=3) dispersal distances of the five most abundant species of Detroit River Hydropsychidae. Means not significantly different from one another are connected by horizontal bars ($p>0.05$, Duncan's test, n=3).

However, our Detroit River samples of Trichoptera were composed primarily of C. campyla and C. speciosa, the species with the smallest source areas. Fewer than 10 percent of these animals would be recruited from outside of an area 4.2 and 4.6 km^2 surrounding the trap site.

Results of contaminant analyses of Hydropsychidae collected simultaneously on opposite banks of the Detroit River are shown in Fig. 12. All quantified PCB congeners were present in significantly higher concentrations in animals from the Detroit side (one-way ANOVA, $p<0.025$). Levels of PC-2 compounds were greater in animals from the Canadian side than from the U.S. side, and pesticide concentrations were equivalent on both sides. Separately analyzed samples of Macrostemum zebratum, a large, filter-feeding caddisfly, yielded similar results (Appendix 2). However, this animal consistently accumulated higher body burdens of OCS and lower burdens of PCBs than did other hydropsychid caddisflies. The filtering net of Macrostemum is of smaller mesh size (5x40 um) than those of other hydropsychid caddisflies (50x70 - 130x250 um; Wallace 1975), which may partially account for the observed differences in contaminant uptake.

Our results accurately reflect local differences in Detroit River sediment contamination as measured by previous studies. Thornley and Hamdy (1984), and UGLCCS (1988) reported considerably higher sediment PCB concentrations on the U.S. side of the Detroit River than on the Canadian side. Elevated levels of PC-2 compounds in Hydropsychidae caught on the Canadian riverbank relative to those from the US bank may be due to the lack of lateral mixing of river water as it travels downstream from the St. Clair River through Lake St. Clair to the Detroit River (Great Lakes Institute 1986). Inputs of these compounds to the St. Clair River are primarily on the Canadian side (UGLCCS 1988). Cross-river differences in contamination of adult aquatic insects suggests limited

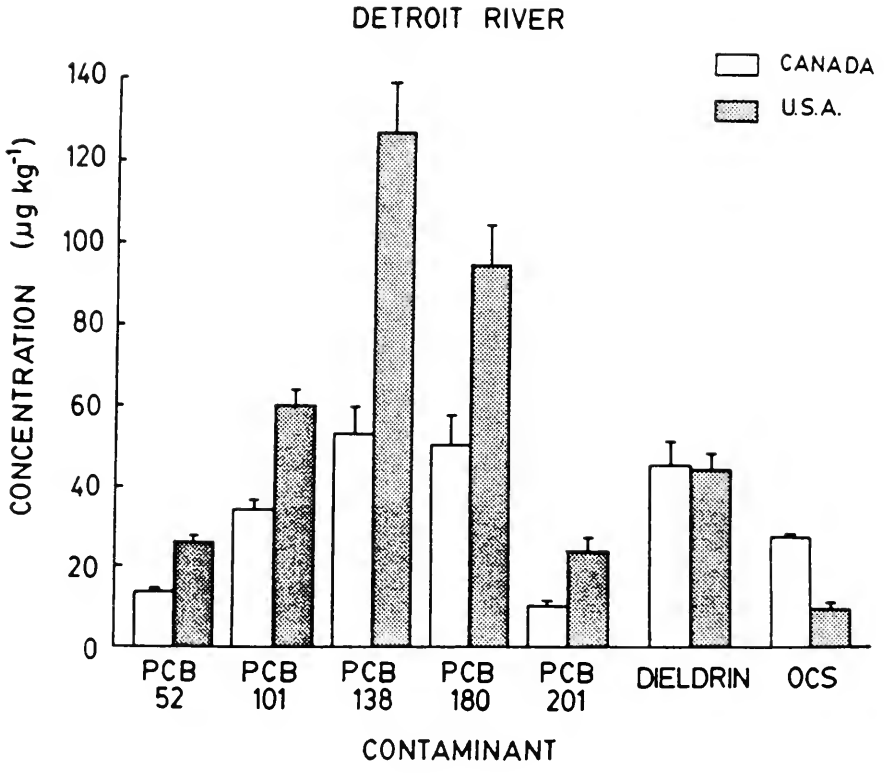

Figure 12. Mean (±1 S.E., n=3) concentrations of representative compounds in Hydropsychidae captured on the U.S. and Canadian banks of the Detroit River.

dispersal, confirming our findings during the dispersal distance studies.

3.3.7. Seasonal Variation

3.3.7.1. Abundance of Aquatic Insects

Caddisfly biomass (fresh wt./trap/2 h) collected on single nights was plotted against calendar date for all sites (Fig. 13). Trap collections during most of May 1987 yielded very small (<2 g) samples. The first large sample (16 g) was collected on 26 May at Station 1. Thereafter, catch sizes increased steadily through June to a maximum on 23 June at both Detroit River sites. Samples collected at St. Clair River stations were much smaller, and only began to increase towards the end of June. In general, caddisfly numbers peaked in late June in 1987, and declined through July and August with several minor peaks occurring later in the season.

Numbers of Hexagenia were low during most of the summer in both rivers except for a two-week period in late June. At Station 1 (River Canard), the maximum number of Hexagenia caught during the 2 h collecting period in 1987 was only 11 animals.

Results of stepwise multiple linear regression analysis are listed in Table 11. Air temperature, (air temperature)^2, wind velocity, and percent cloud cover were significantly correlated with size of light trap catches. Of these factors, air temperature explained the largest proportion (0.36) of the total variation (Figure 14).

3.3.7.2. Contaminant Concentrations

Contaminant burdens of adult caddisflies collected from the Detroit and St. Clair rivers varied with time. PCB concentrations varied little from June to August in St. Clair River Hydropsychidae (Fig. 15), excluding the single replicate of the small August sample from the downstream station, which con-

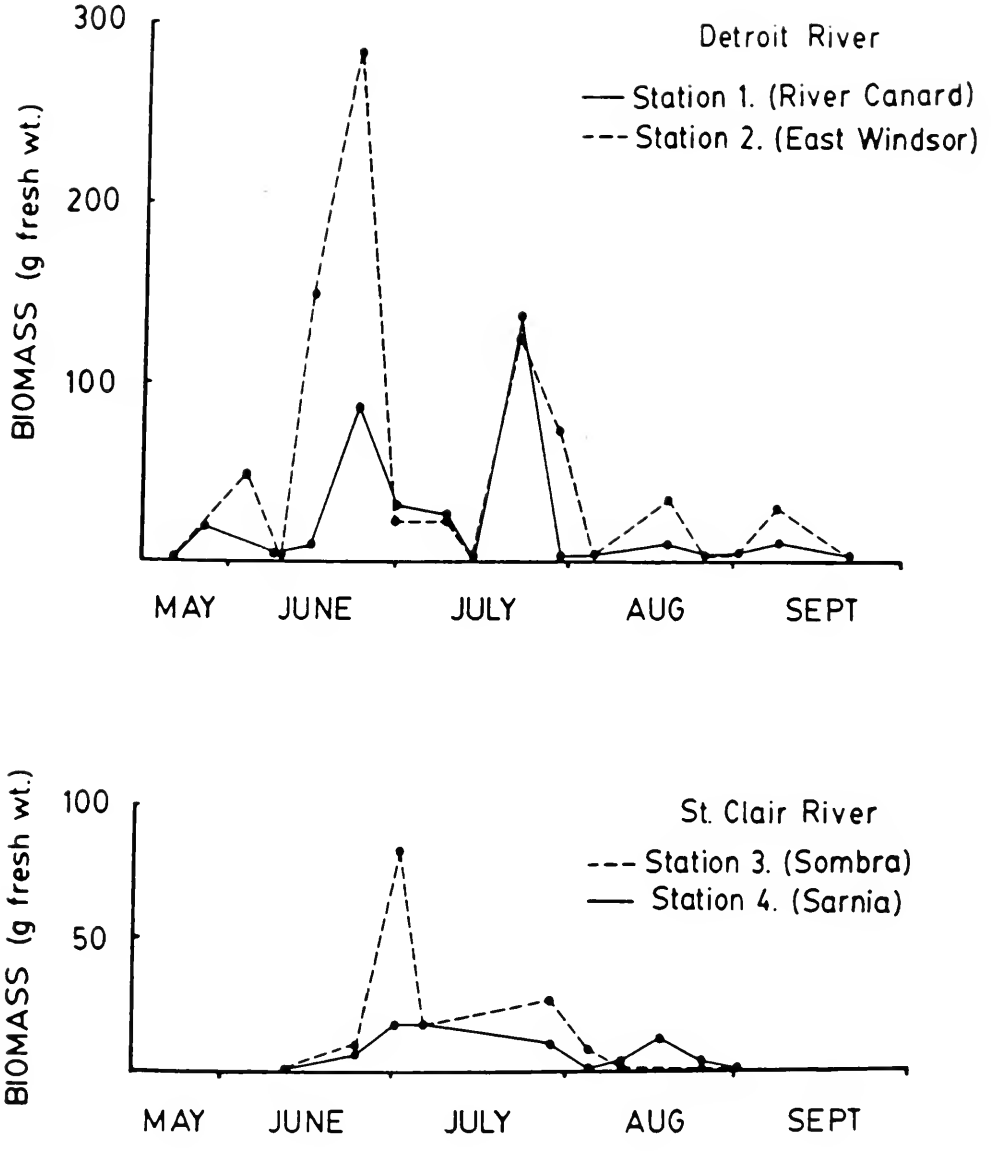

Figure 13. Seasonal variation in abundance of Trichoptera in light traps, May to September, 1987. Note that scales differ on Y-axis.

Table 11. Regression coefficients and coefficients of determination for factors significantly influencing Ln(fresh weight) of light trap samples.

Factor	Regression coefficient	S.E.	R^2
Intercept	-8.835	--	--
Air temperature	0.998***	0.266	0.358
Wind velocity	-0.064**	0.019	0.094
Percent cloud cover	-0.013***	0.004	0.056
(Air temperature)^2	-0.019**	0.006	0.058
Total			0.566

** $P<0.01$, *** $p<0.001$

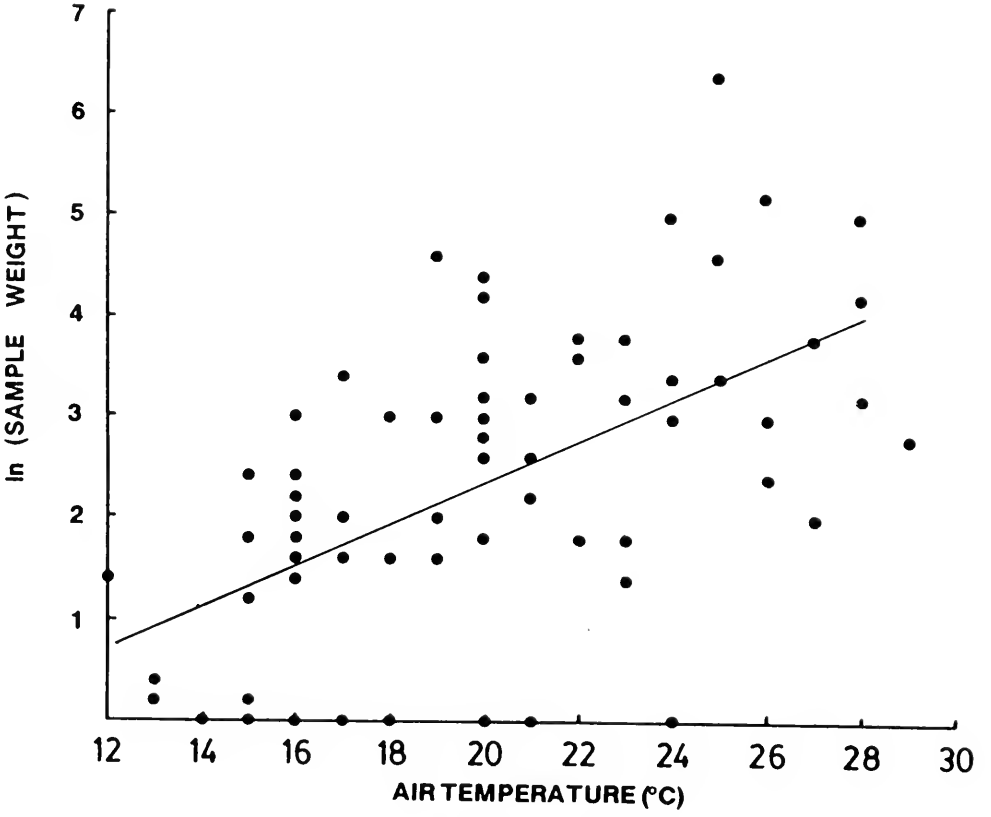

Figure 14. Relationship between air temperature and ln(fresh weight) of light trap catches.

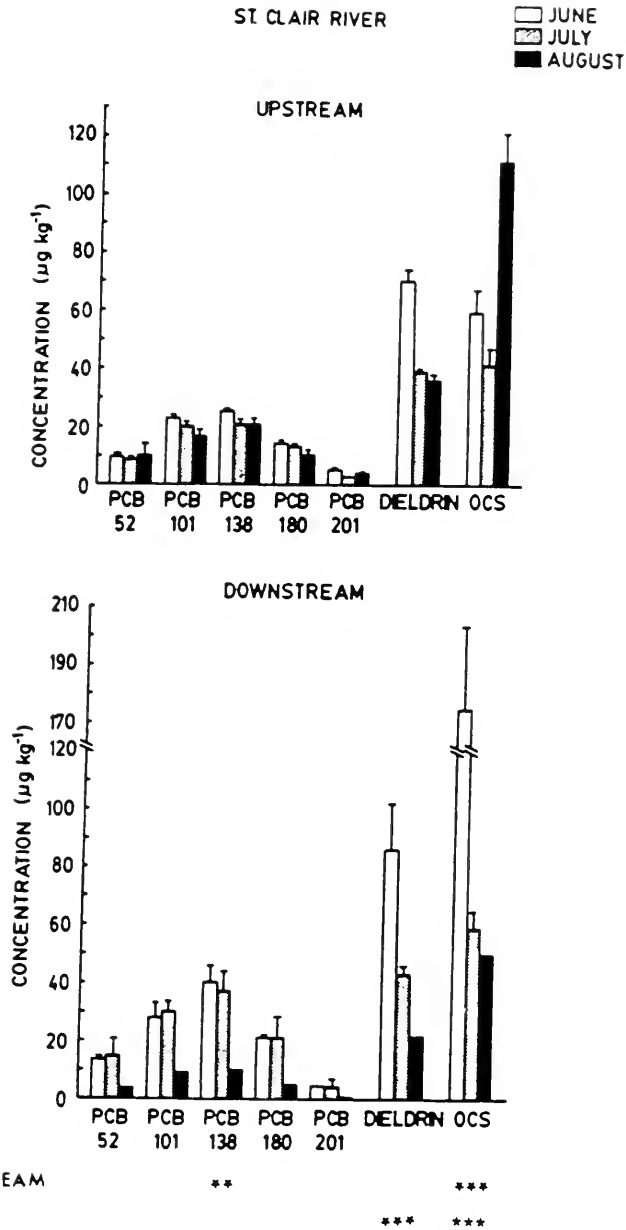

Figure 15. Mean (±1 S.E., n=3) concentrations of representative compounds in Hydropsychidae collected at different times at the St. Clair River. Results of two-way ANOVA testing for upstream/downstream and temporal variation in contaminant concentrations are indicated by asterisks (* $p<0.05$, ** $p<0.01$, *** $p<0.005$, **** $p<0.001$).

sisted of mixed Trichoptera. Concentrations of pesticides and PC-2 compounds varied significantly during the same time period. Concentrations of most PCB congeners and PC-2 compounds varied significantly with time in Detroit River Hydropsychidae (Fig. 16), whereas levels of pesticides remained relatively constant during the summer months.

3.3.8. Passive Light Trapping

Traps operated for 2 h and overnight collected similar weights of insects (one-way ANOVA, $p>0.5$). The variation in numbers of insects caught between 2 h and overnight traps was no greater than that seen between replicate traps (Table 12). Specific composition of Trichoptera caught was similar at all traps (replicated G-test, $p>0.1$). Contaminant analyses revealed no significant differences between body burdens of hydropsychid caddisflies collected during the different sampling periods (one-way ANOVA, $p>0.5$, Table 13). Unattended overnight trapping of adults yields samples with similar specific composition and contaminant burdens as attended traps operated for 2 h following sunset.

3.3.9. Interfamilial Comparisons

Animals in different families of Trichoptera contained different concentrations of contaminants (Fig. 17). Contaminant burdens of St. Clair R. leptocerid caddisflies were significantly lower than those of hydropsychids collected at the same station (one-way ANOVA, $p<0.05$), with the exception of OCS. However, Leptoceridae also contained lower amounts of lipids than Hydropsychidae(Leptoceridae 8-10% vs.Hydropsychidae 18-24%,based ondryweight), which limits our ability to ascribe the observed differences in contaminant burdens to feeding type. Psychomyiidae collected at the Niagara River also contained significantly lower amounts of contaminants than Hydropsychidae, and lower (12-17%) lipid contents as well. Thus, while we found significant interfamily

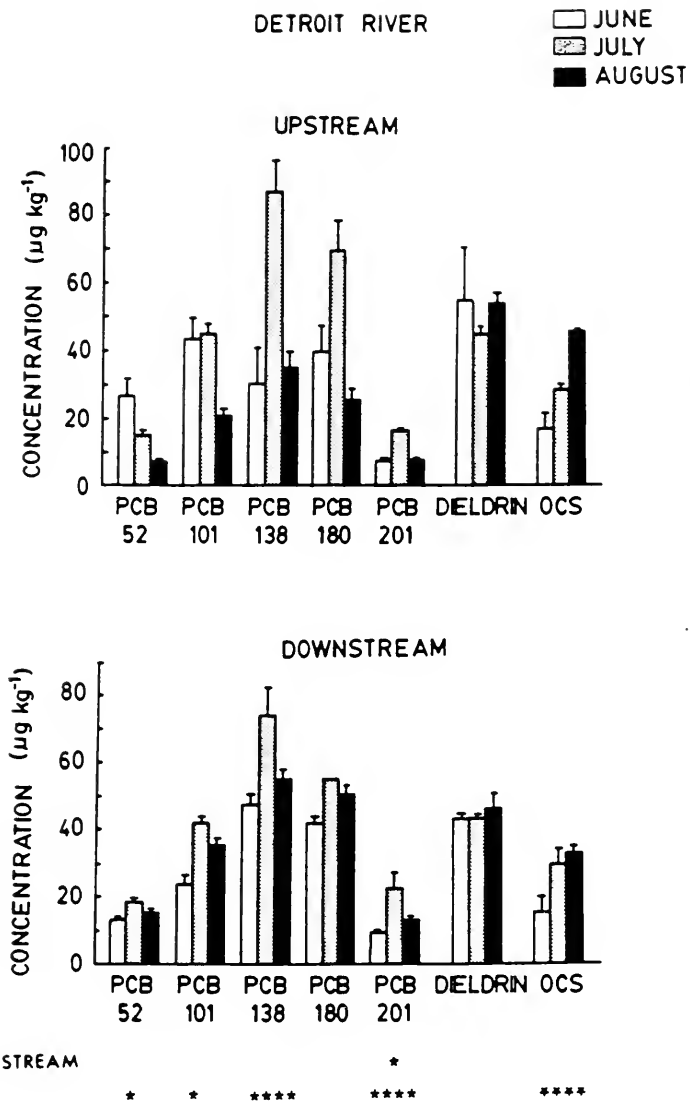

Figure 16. Mean (±1 S.E., n=3) concentrations of representative compounds in Hydropsychidae collected at different times at the Detroit River. Results of two-way ANOVA testing for upstream/downstream and temporal variation in contaminant concentrations are indicated by asterisks (* $p<0.05$, ** $p<0.01$, *** $p<0.005$, **** $p<0.001$).

Table 12. Taxonomic composition of samples collected by attended (2 h) and unattended (overnight) light traps. Total sample weights are indicated in parentheses.

Taxon	Trap 1 2 h (37.711 g)	Trap 2 Overnight (38.970 g)	Trap 3 2 h (51.827 g)	Trap 4 Overnight (61.096 g)
Hydropsyche phalerata	38	32	37	36
Hydropsyche alterans	20	25	13	21
Cheumatopsyche campyla	1	6	3	3
Cheumatopsyche speciosa	1	2	3	2
Macrostemum zebratum	1	1	3	3
Leptoceridae	38	32	40	35
Psychomyiidae	1	2	1	0
Total no. examined	100	100	100	100

Table 13. Concentrations of representative contaminants in Trichoptera samples from 2-h attended traps and overnight unattended traps.

Trap type	Contaminant ($\mu g\ kg^{-1}$ dry wt.)						
	PCB 52	PCB 101	PCB 138	PCB 180	PCB 201	Dieldrin	OCS
2-h (attended)	32.34 (6.428)	79.43 (9.618)	158.53 (16.298)	133.99 (11.529)	28.71 (3.530)	27.02 (3.191)	30.91 (1.972)
overnight (unattended)	31.53 (3.459)	85.17 (8.322)	143.14 (8.418)	115.76 (12.181)	22.543 (0.817)	29.91 (0.158)	26.86 (4.310)

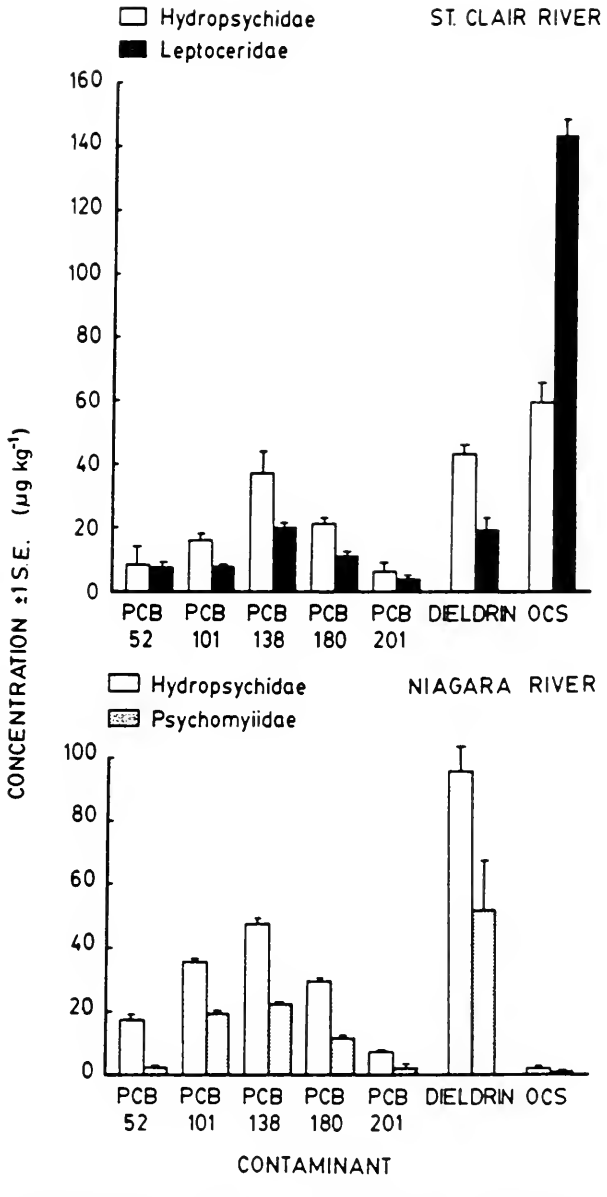

Figure 17. Comparisons of contaminant concentrations among different families of Trichoptera collected at the same location.

differences in contaminant burdens of Trichoptera, we are unable to attribute the differences to either feeding type or lipid levels with certainty.

3.3.10. Comparison of Contaminant Burdens of Animals Differing in Lipid Content

Males of Hexagenia and Macrostemum contained significantly higher amounts of lipid than females (Table 14; Hexagenia, $p<0.005$; Macrostemum, $p<0.05$, one-way ANOVA). Males of Hexagenia were significantly more contaminated when concentrations were calculated on a whole body (dry weight) basis (one-way ANOVA, $p<0.025$). However, contaminant concentrations were not significantly different on a lipid weight basis ($p>0.25$), suggesting that contaminant burdens are largely lipid controlled in Hexagenia. Macrostemum males were significantly more contaminated than females regardless of method of calculation (lipid weight basis, $p<0.001$; dry weight basis, $p<0.005$, one-way ANOVA). Factors other than lipid content may account for the observed differences in contaminant burdens of animals of different sexes.

Based on our plot of concentration of total quantified contaminants vs. body lipid content (Fig. 18), there appeared to be a linear relationship between contaminant burden and lipid content for animals of mixed taxonomic composition and source area ($r=0.65$, $n=47$, $p<0.001$).

3.3.11. Validation

3.3.11.1. Sample Collection

Niagara River traps quickly attracted enormous numbers of Trichoptera. At several sites, the insects were so abundant that the trap had to be shut off 15 minutes after sunset because the catchment container and funnel were completely filled and all collecting jars were exhausted. We found no Ephemeroptera. Trichoptera composition varied among collection sites (Table 15).

Table 14. Percent lipid and total quantified organochlorine contaminants in males and females of Hexagenia and Macrostemum.

Animal (sex)	% Lipid ±1S.E. (dry wt.)	Total quantified contaminants ±1 S.E. ($\mu g\ kg^{-1}$ dry wt.)	Total quantified contaminants ±1 S.E. ($\mu g\ kg^{-1}$ lipid)
Hexagenia (male)	21.83±0.561	364.8± 9.7	1674.8± 83.5
Hexagenia (female)	18.49±0.145	283.2±18.3	1534.1±111.1
Macrostemum (male)	16.02±0.274	866.7±30.7	5406.0± 98.4
Macrostemum (female)	15.00±0.227	597.9± 9.6	3987.8±106.1

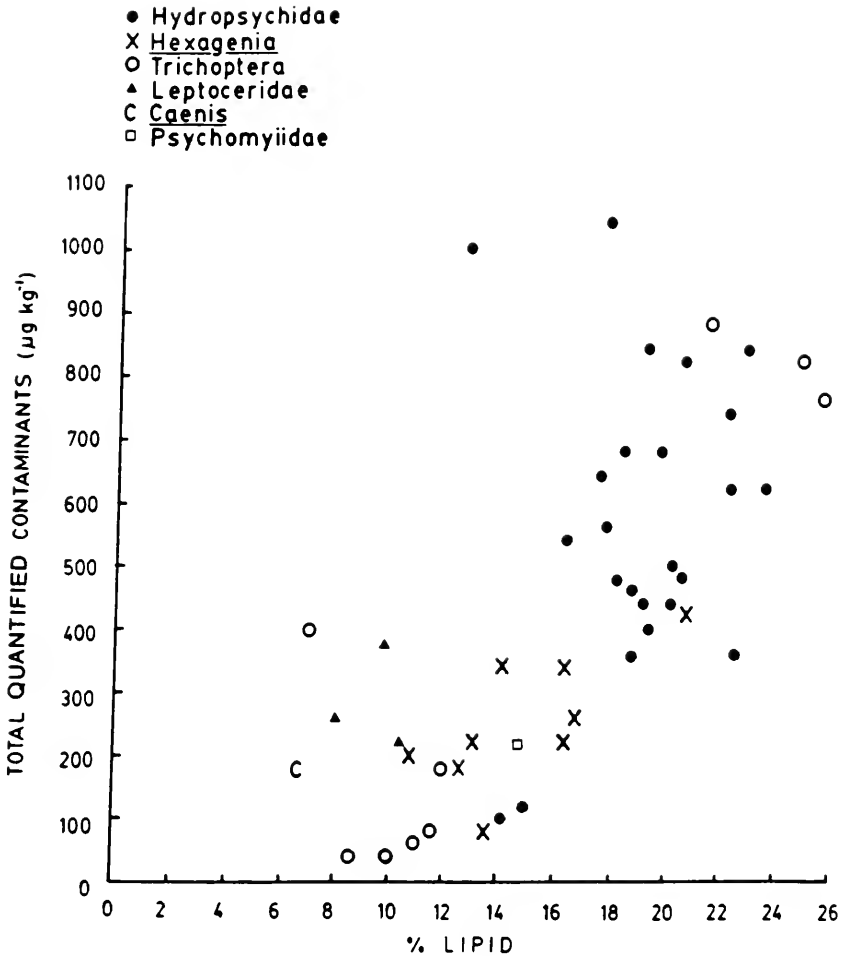

Figure 18. Relationship between lipid content and total quantified contaminant concentration in 1987 and 1988 samples.

Table 15. Relative taxonomic composition (per cent) of Trichoptera collected at the Niagara River. Numbers in bold face are family totals.

Taxon	Sampling station 1	2	3	4	5
Hydropsychidae	**83**	**68**	**90**	**0**	**4**
Cheumatopsyche spp	58	14	41	--	4
Hydropsyche spp	17	54	49	--	--
Potamya sp.	8	--	--	--	--
Leptoceridae	**18**	**32**	**13**	**100**	**94**
Ceraclea spp	18	11	13	100	92
Oecetis spp	--	--	--	--	2
other genera	--	21	--	--	--
Polycentropodidae	**0**	**0**	**9**	**0**	**2**
Neureclipsis sp.	--	--	8	--	2
Polycentropus sp.	--	--	1	--	--
Total No. examined	101	100	103	100	100

Weather was cold and rainy during the June and August collection periods on the St. Marys River. Trichoptera samples collected were small and taxonomically diverse. A few Hexagenia adults were observed swarming during early evening at Pine Island in June but they were not attracted to the trap. An unusually early emergence of Hexagenia from the St. Marys River (D. Schloesser, Michigan Dept. of Natural Resources, personal communication) coupled with unseasonably cool temperatures during the collection periods may have contributed to the low abundance of these animals at trap sites.

3.3.11.2. Contaminant Concentrations

3.3.11.2.1. St. Clair River

Hydropsychidae collected at St. Clair River stations contained the highest levels of HCB, OCS, and QCB recorded among all connecting channel samples, and elevated levels of PCBs and pesticides.

Octachlorostyrene and associated compounds are found in high concentrations in St. Clair River sediments along the entire length of the river (UGLCCS 1988). Concentrations of PCBs are elevated in bottom sediments along the industrial waterfront, south of Sarnia (corresponding to Station 4; UGLCCS 1988). Concentrations of PCBs in sediments downstream of this area may also be elevated due to inputs from electrical power generating stations, and/or downstream transport. High concentrations of OCS and associated compounds and elevated levels of PCBs were detected in St. Clair River caddisflies, corresponding to this trend (Fig. 15). No previous reports of sediment pesticide contamination were available for comparison. Significantly higher concentrations of OCS and PCB 138 were detected in insects collected at the downstream station (Fig. 15).

3.3.11.2.2. Detroit River

Detroit River Hydropsychidae harboured high levels of PCBs, and elevated levels of all other quantified contaminants (Fig. 16). Although concentration of PCB 201 was significantly greater in downstream samples (Fig. 16), no other spatial trends were detected along the river.

Significant recent inputs of PCBs to Detroit River sediments have been reported by UGLCCS (1988) and Thornley and Hamdy (1984). Concentrations of PCBs in insects were high, and appeared to parallel sediment contamination pattern. Elevated concentrations of OCS and associated compounds most likely reflect downstream transport of these compounds from the St. Clair River. The most likely source of elevated pesticide levels in Detroit River caddisflies is agricultural runoff.

3.3.11.2.3. Niagara River

Samples of Hydropsychidae from the 3 upstream stations contained elevated levels of PCBs and pesticides (Fig. 19) relative to hydropsychids from uncontaminated areas. No obvious spatial trend was noted in contaminant burdens in the upper Niagara River. Ceraclea adults (Leptoceridae) from stations 4 and 5 (downstream) harboured much lower levels of all pesticides, slightly lower levels of PCBs, and higher concentrations of PC-3 compounds than Hydropsychidae from stations 1-3.

Kauss (1983) reported elevated (27-48 $\mu g\ kg^{-1}$) total sediment PCB concentrations for the upper Niagara River and the Chippawa Channel, and very high concentrations (up to 2700 $\mu g\ kg^{-1}$) for the lower Niagara River. This trend was reflected in contaminant concentrations in upper Niagara River Hydropsychidae. Sediment OCS concentrations are not available from the Niagara River for comparison to insect contaminant levels. The high levels of pesticides

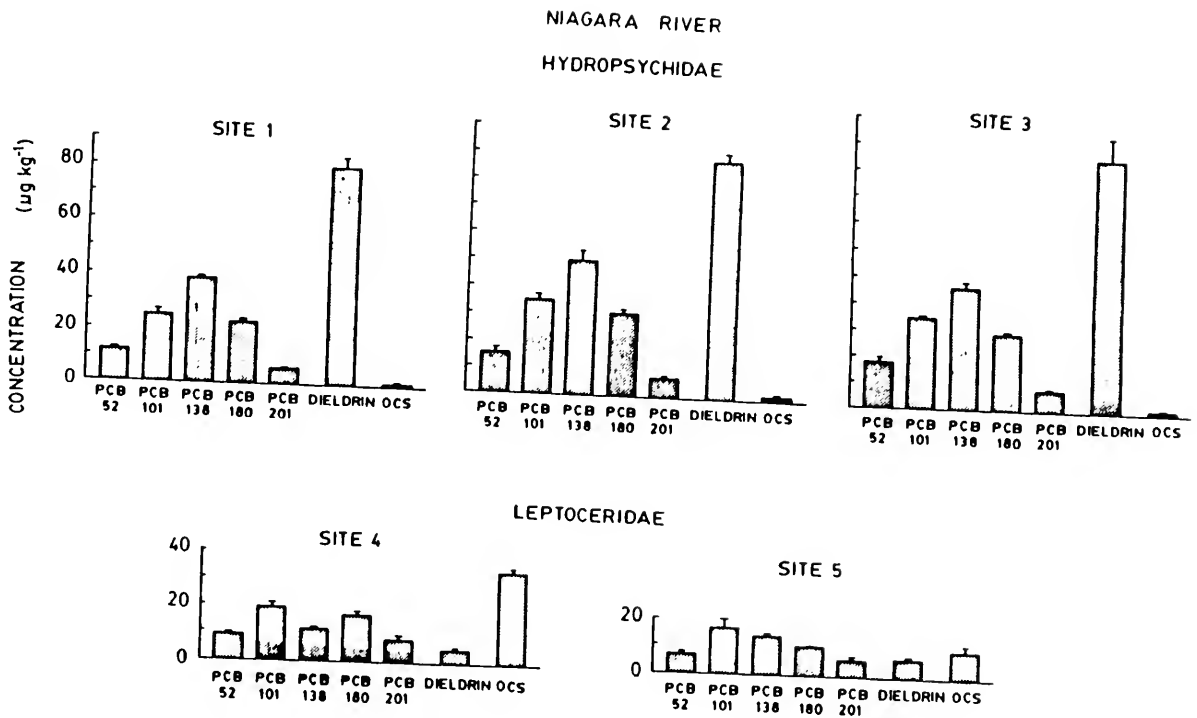

Figure 19. Mean (±1 S.E., n=3) concentrations of representative compounds in Hydropsychidae and Leptoceridae collected at 5 stations along the Niagara River.

most likely reflect runoff from agricultural areas surrounding the river. Low concentrations of OC contaminants were detected in Leptoceridae from downstream sampling stations. The results of interfamilial comparisons suggest that this finding may be at least partially attributed to taxon-related differences in contaminant uptake.

Differences in taxonomic composition of collections among sampling stations at the Niagara River prevented direct comparisons between OC concentrations in animals in upstream and downstream samples. In light of the higher levels and diversity of contaminants in sediments of the middle to downstream reaches (Station 4) of the Niagara River (Kauss 1983, Creese 1987), one may speculate that hydropsychid caddisflies were excluded from the area surrounding this section of the river due to toxic effects. Substrate type and flow appeared to be suitable for development of hydropsychid larvae at Station 4 on the Niagara River (Z.E. Kovats, pers. obs.). However, the extremely large sample of Ceraclea collected from this station suggests that toxic effects are unlikely. Creese (1987) suggested that variation in macroinvertebrate assemblages along the Niagara River is most likely related to substrate type and flow regime (Creese 1987). The potentially great effects of taxonomic differences on insect contaminant concentrations further stress the necessity of using closely related animals for contaminant monitoring.

3.3.11.2.4. St. Marys River

All samples of Trichoptera (all species pooled) were relatively uncontaminated by organochlorine compounds, with the exception of dieldrin, levels of which were also elevated at reference sites. A slight, nonsignificant downstream increase was noted in contaminant concentrations in collected animals (Fig. 20). St. Marys River sediments contain low concentrations of organochlorine contaminants, and point sources of organochlorine contaminant

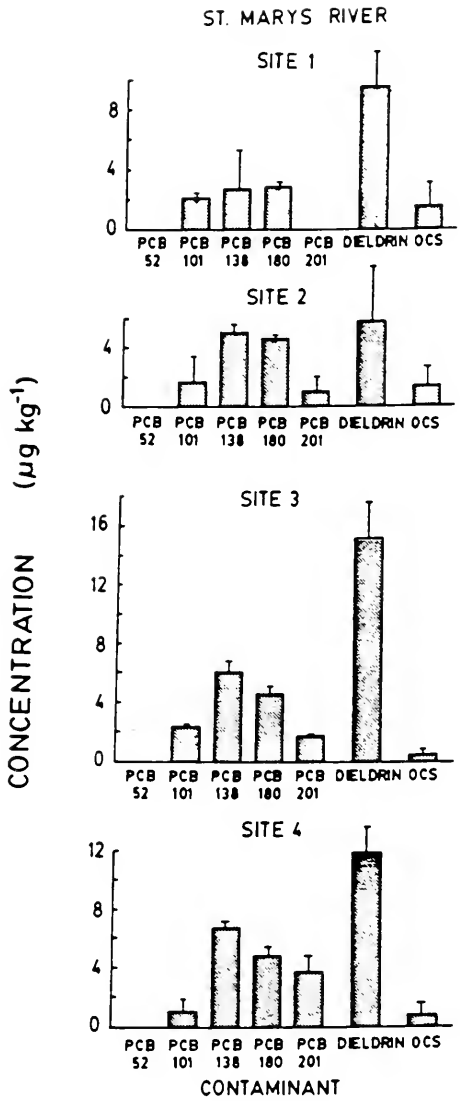

Figure 20. Mean (±1 S.E., n=3) concentrations of representative compounds in Trichoptera (all species pooled) collected at 4 stations along the St. Marys River.

input have not been identified (UGLCCS 1988).

3.3.11.3. Similarity of Contaminant Burdens Among Rivers

Reports of sediment contamination revealed that each of the connecting channels contain sediments contaminated by different types and amounts of organochlorine compounds (Kauss 1983, UGLCCS 1988). If aquatic animals accumulate organochlorine contaminants in proportion to sediment levels, there should be close correspondence between types and levels of contaminants in sediments and the animals sampled. One may expect relative concentrations of contaminants of similar taxa caught at different stations along a river to be more similar to one another than to burdens of the same taxa from a different river. The dendrogram resulting from cluster analysis is shown in Fig. 21. Five groups (clusters) were distinguished by the analysis. Most sampling stations were grouped according to rivers or connecting channel, with the exception of 2 replicate samples of Macrostemum and one relatively small sample of Hydropsychidae (August) from the Detroit River. These samples contained concentrations of PC-3 (OCS, HCB, QCB) compounds more characteristic of St. Clair River samples than of other Detroit River samples.

Cluster I'. Samples of Hydropsychidae from the St. Clair and the upper Detroit rivers formed Cluster I'. These samples were characterized by relatively low levels of PCBs (PC-1), intermediate levels of pesticides (PC-2), and the highest levels of PC-3 compounds, relative to other connecting channel samples (Figs. 21 and 22). Upper Detroit River samples of Macrostemum (replicate samples) were included due to high concentrations of HCB and OCS in those samples. One small (August) sample of Hydropsychidae was included due to high OCS and relatively low PCB concentrations.

Cluster II'. Detroit River samples of Hydropsychidae, with the highest levels

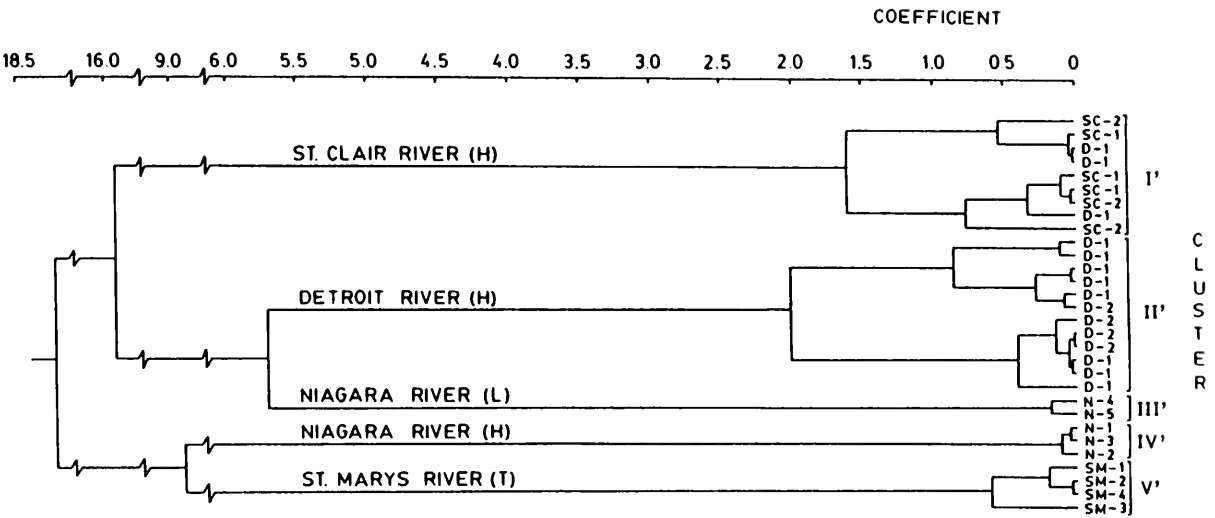

Figure 21. Dendrogram of cluster analysis of samples collected along the Detroit, St. Clair, Niagara, and St. Marys rivers. Numerals I'-V' represent groups discussed in text (D: Detroit River, SC: St. Clair River, N: Niagara River, SM: St. Marys River, L: Leptoceridae, H: Hydropsychidae, T: Trichoptera).

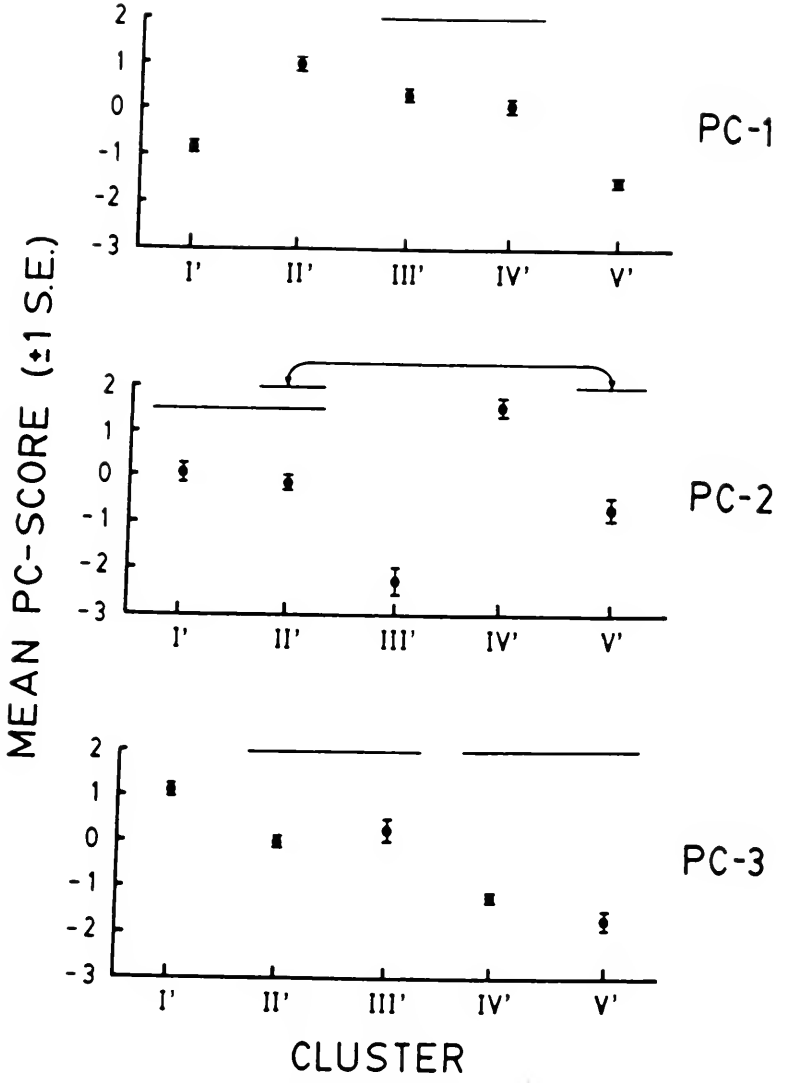

Figure 22. Mean (±1 S.E., n=3) principal component scores of groups distinguished by cluster analysis of samples collected along Great Lakes connecting channels. Means not significantly different from one another are connected by horizontal bars or double-ended arrows ($p>0.05$, Student-Newman-Keuls test, n=3).

of PCBs and intermediate levels of pesticides and PC-3 compounds, relative to other contaminants, comprised this group (Figs. 21 and 22).

Cluster III'. Leptoceridae from lower Niagara River sampling stations formed Cluster III'. These samples contained moderately high concentrations of PCBs, intermediate levels of PC-3 compounds, and the lowest levels of pesticides of the rivers sampled (Figs. 21 and 22).

Cluster IV'. Upper Niagara River Hydropsychidae, in Cluster IV', were moderately contaminated by PCBs, had high levels of dieldrin, and relatively low levels of PC-3 compounds relative to the same animals from the other rivers (Figs. 21 and 22).

Cluster V'. St. Marys River Trichoptera formed this group, characterized by intermediate levels of pesticides, and lowest levels of all other contaminants compared to samples from other rivers (Figs. 21 and 22). This pattern was also observed in samples of Trichoptera from uncontaminated sites (Overall analysis; section 3.2).

In summary, results of the cluster analysis suggest the occurrence of different and characteristic combinations of contaminants in adult Trichoptera emerging from each river sampled. Although differences between concentrations of compounds associated with a given PC were nonsignificant between rivers in some cases (Fig. 22), animals from each river contained a unique combination of contaminants when all 3 PCs were considered. As noted above, differences between contaminant concentrations of upper and lower Niagara River caddisflies may be partially due to taxon-specific patterns of contaminant uptake. In particular, the caddisfly adults collected from each of the rivers carried body burdens consistent with previously reported local sediment contaminant levels.

4. SYNOPSIS AND RECOMMENDATIONS

4.1. Sampling Procedure

Relatively few studies have investigated the use of adult aquatic insects as biomonitors (Ciborowski and Corkum 1988, Clements and Kawatski 1984, Mauck and Olson 1977). These studies demonstrated the presence of PCBs in adults of Hexagenia and caddisflies with body burdens correlating with reported local sediment and suspended sediment concentrations. Although these workers have not described protocols that would be useful in a general monitoring program, Clements and Kawatski (1984) encouraged periodic monitoring of adult insect PCB concentrations as a reasonably accurate method of assessing PCB contamination in rivers. Ciborowski and Corkum (1988) suggested that collection of adults yields an inexpensive alternative to traditional aquatic sampling methods in surveys of organic contaminants in biota.

Our results indicate that adult Ephemeroptera and Trichoptera can be collected in large numbers using standard light traps. Collections yielded sufficiently large samples from all waterbodies sampled to permit analysis by GC for organochlorine contaminants. The collecting equipment was relatively inexpensive and requires no special skills to operate. Unattended traps were equally successful in capturing large numbers of insects and yielded species composition identical to catches in attended traps operated for 2 h. Since Hexagenia were collected manually, our sample estimates reflect the actual mayfly density only for nights when incoming numbers were small enough for one person to collect all specimens alighting on the sheet. This problem did not influence the dispersal distance studies.

Light traps yielded larger numbers of caddisflies with considerably less effort than the manual method used by Ciborowski and Corkum (1988). Light

traps suffer from the same shortcomings as the manual method; sizes of catches are greatly affected by prevailing environmental conditions, especially temperature and wind velocity. Catches were largest on warm nights with wind velocities <10 km h^{-1}, even near the end of the sampling season. Although detailed data are unavailable, relative humidity also seemed to influence catches; larger samples were collected on humid nights. These results imply the necessity of sampling under appropriate environmental conditions.

Bornaud et al. (1983) compared taxonomic composition of adult insect light trap catches with that of larvae colonizing artificial substrate samplers in the Rhône River. They concluded that light traps are more efficient sampling devices than artificial substrate samplers, yielding reliable qualitative and quantitative results regarding local populations. This result may apply to relatively isolated large rivers, where the source of light trap samples can be assigned with certainty. The Detroit and St. Clair rivers are similarly relatively isolated from other large rivers with high current velocities. Of the six species of hydropsychid caddisflies reported from the Detroit and St. Clair rivers, based on collections of larvae by Davis et al. (unpubl.; Cheumatopsyche campyla Ross, C. speciosa (Banks), Hydropsyche phalerata Hagen, H. alterans (Walker), Macrostemum zebratum (Hagen), Potamyia flava (Hagen)) we collected five by light traps (C. campyla, C. speciosa, H. phalerata, H. alterans, M. zebratum), and an additional large river species (Hydropsyche hageni Banks). Therefore, we are confident that most abundant local genera of Trichoptera are represented in light trap samples. However, the data do not reveal whether degree of attraction is influenced by behavioural state or sex of the animals.

To our knowledge, our collections of Macrostemum zebratum represent the first record of the occurrence of adults of this animal in the upper Detroit

River. Several individuals of Macrostemum also were captured at our lower St. Clair River sampling station. Thornley and Hamdy (1984) reported occurrence of Macrostemum larvae only from a relatively short section of the lower Detroit River. Our samples of adults with contaminant levels characteristic of upper Detroit River caddisflies imply significant range expansion of this animal during the period between studies.

4.2. Seasonal Variation in Abundance and Contaminant Concentration

Trichoptera actively entered the traps in sufficient numbers to permit analyses for contaminants from June to late August. Numbers of Hexagenia were relatively low throughout the summer, exhibiting only one pronounced late June peak. Caenis was available sporadically, and only near marshland. If these taxa are of particular interest, we recommend careful timing of collections, at or near the peak emergence period, to ensure sufficiently large samples for contaminant analysis.

Although adult caddisflies emerge throughout the summer months, time of sampling for the taxa selected for contaminant analyses should be carefully chosen. Many species of Hydropsychidae are bivoltine, with an overwintering generation that emerges in late spring/early summer followed by a second generation emerging in late summer (Mackay 1978). Differences in larval development times of collected insects arising from sampling different generations (overwintering vs. summer generation) may partially account for the observed temporal variation in insect contaminant concentrations, due to different durations of contaminant exposure. Sampling for Trichoptera early in the emergence season ensures that contaminants were accumulated during a standard length of time (approx. 1 year), defined by the animal's life cycle.

In the Detroit and St. Clair rivers, the contaminants exhibiting the greatest temporal variation were those with the greatest reported ongoing inputs (UGLCCS 1988). This variation may reflect temporally fluctuating contaminant inputs to Detroit River water and sediments. Although PCBs are no longer produced, industrial waste water and municipal sewer inputs still contribute large amounts of PCBs (approx. 250 kg yr^{-1}) and other organic pollutants to Detroit River sediments (UGLCCS 1988).

Temporal variation in water concentrations of PCBs has been documented by Larsson (1986) and Larsson and Sodergen (1987), due to temperature-dependent release of PCBs from contaminated sediments. Concentrations of PCBs in zooplankton paralleled concentrations in the water, while fish contaminant concentrations exhibited a steady increase during the study period in artificial ponds. Contents of multiplate artificial samples (organisms and sediment) and caddisfly larvae from the Hudson River reflected longer-term (yearly) trends in sediment PCB contamination (Novak et al. 1988). Rice and White (1987) have shown that dredging of rivers may release significant amounts of sediment-bound PCBs, and that the released contaminants were bioavailable to aquatic biota (fish and caged clams). Based on these studies, considerable temporal fluctuations may occur in the amount of bioavailable organochlorine contaminants on both weekly/monthly and yearly time scales. Although data on temporal variation of contaminant inputs into the Detroit River are not available for comparative purposes, our results suggest that monitoring contaminants in adults can reveal yearly and possibly relatively short-term changes in aquatic contamination.

4.3. Choice of Taxa

The animals used in our study were chosen on the basis of availability. However, microhabitat differences within the Trichoptera also warrant consid-

eration when selecting taxa for monitoring contaminants, since the extent of contaminant uptake and the type of compounds accumulated are partially dependent upon larval feeding behaviour and substrate preference. Bush et al. (1985) analyzed caddisfly larvae from the Hudson River and found differences in PCB concentration among members of different species of Hydropsychidae. Possible reasons for this variation were not discussed by these workers. We also found significant differences in contaminant concentrations in animals in different families (section 3.3.9). Accordingly, we recommend that samples used for monitoring be ideally composed of closely related animals, at least at the family level. The Hydropsychidae, composed primarily of filter-feeding riverine species, appear to be the most appropriate group for monitoring contamination in large rivers. The mayfly Hexagenia, where available, seems well suited for monitoring lakes. During our study, the small mayfly Caenis was collected in large numbers only at sampling stations situated near lakes and marshes. However, because Caenis is widely distributed and occurs across a broad variety of habitats (streams, ditches, lakes, rivers; Corkum 1989), it is potentially useful for contaminant monitoring. This animal must be collected in large numbers to reduce the otherwise excessive amount of sorting time required prior to contaminant analysis.

4.4. Emerging Adults and Collections of Larval Trichoptera

Although adults captured in the process of emerging appear ideally suited for point source determination of contaminant concentrations in aquatic habitats, difficulties associated with sampling new emergents render their use in contaminant monitoring programs impractical. Our collections of larvae were generally unsuccessful, or yielded very small samples, both during scoop netting trials and in underwater light traps.

Boat-mounted light traps collected large numbers of adults of Hexagenia and hydropsychid caddisflies. Boat-collected samples of Hexagenia were composed of subimagoes and imagoes. Hexagenia adults must alight on a substrate in order to shed their subimaginal cuticle, suggesting that trapped imagoes had probably emerged away from the immediate vicinity of the light traps, or were returning to oviposit. The value of boat-collected imagoes is no greater in contaminant monitoring than that of shore-collected animals, due to difficulty in sample source assignment. Therefore, subimagoes appear better suited for use in contaminant monitoring than imagoes. In the case of caddisflies, which prefer primarily lotic or littoral habitats, collection by boat-mounted traps is of no additional value, since the bank to mid-channel distance is within the flight range of adults, even in large rivers.

Collections of larvae by various short-term sampling methods (grab samplers, manual collection, artificial substrate sampler employed for 10 d) failed to yield samples of sufficient size for contaminant monitoring, with the exception of manual collection from nearshore and shoreline rock/concrete surfaces. Although the success of manual sampling and ease of sample source determination is encouraging, it suffers from several disadvantages. Larvae of the dominant species of Hydropsychidae collected (Hydropsyche alterans) prefer wave-washed shoreline rocks (Schefter and Wiggins 1986), and larvae often do not come into contact with bottom sediments. Moreover, larvae collected were of various sizes, representing different contaminant exposure periods. Manual sampling may be a viable technique in streams, where the entire stream bottom is accessible for sampling. Since larvae of mayflies and caddisflies are known to drift in relatively high numbers, especially at night (Waters 1972), drift nets lowered to the river bottom may be useful for collection of benthic caddisfly larvae.

4.5. Comparison of Contaminant Concentrations in Larvae and Adults

Our collection of hydropsychid larvae yielded samples with similar types (relative proportions) of contaminants as adults, but with lower concentrations. Hydropsychids feed and grow continuously during their larval period up to the 5th instar (pre-pupa) stage, with the exception of a period of reduced activity in the winter. If feeding contributes to contaminant burden, accumulation of contaminants should be continuous throughout larval development. Therefore, the length of time spent on or in the substrate may be correlated with contaminant concentration. Most of the larvae used in our comparison were 2nd to 3rd instar, implying that the period during which they accumulated contaminants was relatively short, compared to adults. This may partially explain the proportionally lower contaminant concentrations in the larvae analyzed. Adult concentrations also exceed larval concentrations owing to the potential for concentration of contaminants into a smaller body volume as certain reserves are metabolized during pupation.

Studies of contaminant burdens in aquatic larvae rarely consider or report the developmental state of the larvae (early vs. late instar; Bush et al. 1985, Novak et al. 1988). This clearly may present an important source of variation in field studies that deserves further attention. Presumably, such variation is reduced through the use of adults, all of which by definition have reached the same developmental stage.

4.6. Minimum Sample Size and Detection Limits

Results of our analyses indicate that larval aquatic insects accumulate significant concentrations of organochlorine compounds and retain sufficient amounts as adults to permit precise analysis by GC. Minimum sample size experiments have shown that a relatively small sample biomass (1.2 - 2.5 g,

fresh wt.) of adult insects is adequate to provide acceptable precision in analytical results (coefficient of variation $\leq$20% with triplicate samples). This may be attributed to the relatively low water content and high lipid content of adult aquatic insects.

Comparisons of contaminant concentrations between animals from industrialized versus reference areas confirmed that aquatic insect adults are sensitive indicators of organochlorine contamination. Samples from reference sites contained detectable amounts of most (>85%) of the compounds studied. Organochlorine concentrations were significantly lower in reference samples than in those from contaminated sites, with the exception of some pesticides. We attribute occurrence of the compounds detected in samples from non-industrial sites to agricultural inputs (Watt 1988) and aerial deposition (Rappaport et al. 1985, Metcalfe and Macdonald 1988). Ideally, rearing larvae in sediments dosed with various concentrations of contaminants, and subsequent analysis of adults would be the next step to permit better calibration and interpretation, so that typical overall sediment contaminant levels could be estimated from analyses of field-collected adults.

Overall Analysis

Cluster analysis of all 1987-1988 samples revealed differences in contaminant concentrations among insect samples according to source area, taxon, and other factors. The effect of source area appeared to override that of taxon in Cluster III (samples of Hexagenia and caddisflies from the Lake Erie-Lake Huron Connecting Channel). In this cluster, subgroups formed, with homogeneous taxonomic composition (Hydropsychidae and Hexagenia). Taxonomic differences in sample composition were important in the case of Niagara River animals (Clusters II and V). Cluster IV was the most homogeneous cluster, both in taxonomy and organochlorine contaminant concentrations, consisting

almost exclusively of Detroit River Hydropsychidae. In the case of the Niagara and St. Clair rivers, animals in different families of Trichoptera contained widely differing contaminant concentrations.

Assignment of differences in contaminant concentrations to taxonomic differences from a given geographic area should be done with caution, since it is not possible to ascertain exact source areas of light trap-collected insects. Nevertheless, for animals selected in this study as indicators of organochlorine contamination (Hydropsychidae, Hexagenia), we detected good general correspondence between insect contaminant concentrations and reported sediment contaminant levels.

Several samples were classified as belonging to clusters other than those expected, based on sample sources. One sample of the mayfly Caenis, collected from Lake Scugog occurred in Cluster II (Niagara River Ceraclea and St. Clair River Trichoptera) due to elevated PCB concentrations in these animals. Psychomyiidae from the midreaches of the Niagara River, containing low levels of PCBs and "other" organochlorine compounds and elevated levels of pesticides, was assigned to Cluster I (reference samples). Taxon-specific patterns in uptake of contaminants may explain these findings. One 1987 sample of upper Detroit River Trichoptera occurred in Cluster V (Niagara River Hydropsychidae), due to elevated pesticide concentrations, which is more characteristic of Niagara River samples. Temporal variation in contaminant concentrations of Detroit River Trichoptera may account for the apparent misclassification of this sample.

The similarity in contaminant concentrations in animals from various reference areas suggests similar levels of contamination in those areas. Aerial deposition is the most likely source of contaminants to remote areas

(Rappaport et al. 1985, Metcalfe and Macdonald 1988). Although these sites were grouped together partially due to low levels of most contaminants, it remains possible that the areas sampled are subject to similar types and amounts of contaminant input. Relative magnitudes of concentrations of representative compounds were similar in samples from each reference area, suggesting a homogeneous contaminant mixture encountered by benthic animals in these habitats. The compounds detected in samples from reference areas may be representative of those compounds cycling in the biosphere (Baumann and Whittle 1988).

The overall cluster analysis suggests that although organochlorine contaminant concentrations in adult aquatic insects exhibit good general correspondence to sediment contaminant levels and types, taxon-related differences in contaminant uptake may interfere with the interpretation of results. Thus, it is important to analyze animals as closely-related as possible, at least at the family level. In cases where considerable differences in feeding type and microhabitat use exist between confamilial animals, one should limit analyses to congenerics or conspecifics.

4.7. Dispersal Distance Studies

The primary goal of our study was to demonstrate the utility of adult Ephemeroptera and Trichoptera as indicators of local contaminant levels. Therefore, it was important to delineate the area to which samples pertained. Ideally, animals would be attracted from a relatively small area surrounding the sample station (Section 3.3.6). If animals disperse randomly from emergence points, the number of animals decreases exponentially with distance from the source. In our studies, the lake or river margin was considered to be the "source" of the insects collected. However, emerging mayflies and

teneral (immature adult) caddisflies frequently move inland where they become sexually mature (Svensson 1974). Following mating, the females return to the water to oviposit. Therefore, greatest densities might be expected at the water's edge and/or some distance inland, depending on a species' behaviour.

Peaks in numbers of animals were observed both at the shore (Cheumatopsyche campyla, Cheumatopsyche speciosa, Hexagenia) and at some distance inland (Hydropsyche phalerata, Hydropsyche hageni, Macrostemum zebratum, Hexagenia). Records of times of first appearance among dispersal sample sites also suggest that at least in some cases Hexagenia were returning from inland to the lake.

The median and 10 percent dispersal distances for Hexagenia, Cheumatopsyche, and Hydropsyche suggest that one-half of total light trap catches come from a 0.43-3.78 km^2 area around each of the sample sites, depending on the species collected. Ninety per cent were attracted from within an area encompassing up to 20 km^2. Estimates for Macrostemum were greater (Table 10), but dispersal data for only one replicate was analyzed for this strong-flying caddisfly. However, taxonomic composition of light trap samples was dominated by Cheumatopsyche species, which had the lowest measured dispersal abilities.

Animals that inhabit the midregions of large waterbodies must be strong fliers if they are to transform (from mayfly subimago to imago) or mate on land. This may limit the certainty with which contaminant levels in adults of these species can be attributed to specific point sources of contamination (e.g., single outfall pipes). Alternative sampling designs, such as multisite trapping and triangulation of likely contaminant sources might be necessary to circumvent this problem if Hexagenia, Hydropsyche, or Macrostemum are to be the organisms of choice. Although Cheumatopsyche species dispersed con-

siderably shorter distances, localization of point sources may still be difficult using our protocols, due to the tendency of caddisflies to disperse along rivers, especially upstream (Roos 1957). Sex-related differences in dispersal abilities may also complicate sample localization.

Since animals dispersing inland from the shore are most likely to encounter those light traps located near the shore, samples collected during a single evening may not be independent, resulting in autocorrelation in the data set (Odland 1988). This effect is minimal on evenings with little emergence. The relative contributions of emerging adults and those already inland are difficult to estimate, rendering it difficult to predict the degree of autocorrelation which may be expected on any given evening of sampling. The design of future studies of aquatic insect dispersal should take the possibility of this effect into consideration.

Additional studies are required to gain sufficient understanding of caddisfly dispersal patterns. Nevertheless, our dispersal data indicate that insect samples are sufficiently localized to permit us to confidently assess local overall sediment conditions within a single reach of a river.

4.8. Relationship Between Contaminant Concentration and Lipid Content

Our analyses of male and female adults suggest that the relationship between contaminant concentration and lipid content of aquatic insects is complex and may be species-specific. Total organochlorine contaminant concentration appeared to be related to lipid content of Hexagenia adults, but this was not the case for Macrostemum. Significantly greater contaminant concentrations in males of Macrostemum may result from differences in feeding rates and metabolic efficiency, or may possibly be due to physiological differences between males and females, as well as differing lipid contents or dispersal

distances. Explaining differences in contaminant concentrations on the basis of differing lipid contents alone appears to be valid only for certain species, and only for a given geographic location, where all animals are exposed to the same set of contaminants.

At broader taxonomic levels, (genera and families) no simple relationship was obaerved between lipid content and contaminant concentration. For example, Hydropsychidae from the upper Detroit and Gull rivers had similar lipid contents, ranging from 12-17 percent, but exhibited tenfold differences (100-1000 $\mu g\ kg^{-1}$) in contaminant concentrations. Similar, but less dramatic contrasts were obtained for Hexagenia and Leptoceridae. In these cases, contaminant level in the animals' habitat was clearly more important then lipid content in influencing contaminant burdens. Taxonomic composition of other samples included in our overall regression was heterogeneous at the generic or family level, allowing no further comparisons.

The relationship that we found between total extracted contaminants and lipid content suggested that an overall correspondence between lipid content and contaminant concentration exists among animals of mixed taxonomic composition (Hydropsychidae and Hexagenia). However, our collections of Hydropsychidae and Hexagenia represented different source areas, as well as different microhabitats and feeding types. Owing to the close correspondence of contaminant concentrations of animals to the extent and type of sediment contamination in their rivers or lakes of origin (section 3.3.11.3), we suggest that source area is a more important controlling factor of contaminant concentrations than lipid content. The effect of microhabitat and feeding type on contaminant concentration is difficult to evaluate, but may also influence contaminant uptake. Considering these factors, the lipid content-contaminant concentration relationship observed becomes artificial. Thus, one must

exercise caution when attributing contaminant levels of animals to variation in lipid content at any taxonomic level, since source area, microhabitat, and feeding type may also affect contaminant uptake. Because of the uncertain relationship between lipid level and body contaminant concentration, we recommend that organochlorine contaminant concentrations be reported on a dry weight basis, but that information on both lipid content and moisture content also be provided for each sample.

4.9. Validation

Our objectives during the validation part of our study were to obtain adequate material for GC analysis from each of the rivers sampled, and to demonstrate that contaminant concentration of collected animals correspond to reported sediment contaminant levels at each locality. Our collections yielded sufficient biomass at all locations for GC analysis of at least 2 replicate samples, fulfilling our first objective. Cluster analysis suggested the occurrence of different and characteristic combinations of contaminants in animals from each of the rivers sampled. Taxonomic differences in contaminant uptake may complicate data interpretation (Niagara River Hydropsychidae and Leptoceridae), and this suggests the need for standardizing the taxa used for contaminant monitoring. Overall, contaminant concentrations of adult insects were consistent with local sediment contamination as reported by previous studies, corresponding to our second objective. Thus, we were able to demonstrate general applicability of our biomonitoring protocols over a range of geographical and ecological conditions.

4.10. Conclusions

We believe that use of our protocols for collecting and analyzing adult insects produces replicable and reliable contaminant data suitable for long-

term monitoring in Areas of Concern. Our studies have shown good general correspondence between contaminant concentration in light-trapped animals and reported levels of organochlorine contaminants in the sediments. The sampling equipment is portable, inexpensive, and simple to operate, yielding large samples of adult insects. Sorting and processing time is short compared to benthic sampling, and analytical results for replicate samples are consistent. The attractant area sampled is sufficiently large to yield an integrated view of organic contamination in the bay of a lake or an approximately 2 km long reach of a large river (1 km on either side of the trap), yet still allows detection of relatively small-scale spatial trends in sediment contamination.

In addition to their value in monitoring large waterbodies, we feel that the portability of light traps may make them especially well suited for use in preliminary or synoptic monitoring studies of aquatic contamination in remote areas previously not surveyed.

4.11. Recommendations for Future Work

The following laboratory and field studies are recommended to elucidate the relationship between contaminants in sediments and their uptake and transfer through developmental stages of aquatic insects.

Laboratory studies of contaminant uptake from sediments with known chemical concentrations and organic carbon and/or oil content by larvae of species of aquatic insects commonly captured in light traps would provide valuable information on the relationship between sediment contaminant levels, partitioning effects and concentrations in animals. Analyses of contamination levels in adults of these laboratory-reared larvae would allow prediction of sediment concentrations of contaminants in the field. Contrasts of results of laboratory bioaccumulation studies of Trichoptera larvae with differing feed-

ing habits would be especially useful in resolving some difficulties in interpreting the significance of differences in contaminant concentrations among light trap catches of adults.

Simultaneous collections of adults and sediment from contaminated areas is necessary for further clarification of the relationship between adult and sediment contaminant concentrations. Different dilutions of field collected sediments may also be used for rearing larvae until emergence, allowing comparisons of contaminant concentrations among laboratory-reared and field collected animals.

In light of the differences we found between contaminant levels of males and females, sex-related and lipid-related differences in contaminant uptake also warrant additional consideration. Additionally, further dispersal studies to examine upstream dispersal of commonly light trapped species may allow more precise assignment of sample sources.

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APPENDICES

6.1. APPENDIX 1.

Protocol Summary

6.1.1. Light Tap Construction -- Refer to Fig. 1 for exact design of light trap.

6.1.2. Required materials.

1. Aluminum top plate (diameter: 38 cm, thickness: 2-3 mm, with 3 cm circular central hole for insertion of UV light); custom built.

2. Transparent vanes (3 per trap, width: 15 cm, length: 45 cm, polystyrene or acrylic replacement window panes; available at hardware supply stores). Cut to size and proper angle to fit funnel with utility knife. Fasten to top plate using 5 cm long steel straps bent to 90° angle. Drill holes through top plate and vanes as necessary for attachment of vanes. Vanes should be attached to one another at bottom using steel straps.

3. Ultraviolet light and adapter for attachment to batteries (15W, DC Night Collecting Light, BioQuip Products, P.O. Box 61, Santa Monica, CA 90406; DC Pigtail Adapter, BioQuip Products).

4. Batteries (one 12V or two 6V lantern batteries, available at hardware supply stores, or automobile battery; connect 6V batteries in series).

5. Funnel (top diameter: 30 cm, should be chosen to fit mouth of bucket; available at wine makers' suppliers).

6. Bucket (galvanized metal, top diameter: 30 cm; may require three steel clips to fasten funnel to bucket; available at hardware supply stores).

7. Sample reservoir (diameter: 12 cm, height: 20 cm; made of aluminum hardware cloth (window screening), by stapling at seams).

8. Dry ice (approx. 2 kg per hour of collection). Gardening gloves are recommended for handling.

9. Cotton bed sheet (1.2x1.7 m (one-half of regular twin size)).

10. Collecting jars (2 per trap; 500 mL, cleaned with detergent and rinsed three times with Hexane (distilled in glass (suitable for GC analysis))

11. Cooler for storage of dry ice and transport of specimens.

12. Thermometer, psychrometer, and anemometer for measuring meteorological conditions.

6.1.3. Collecting Procedure

Light traps should be used on calm (wind velocity <10 km h^{-1}), warm (>20°C) and humid evenings. Windy conditions, low temperatures, and precipitation reduce the number of insects caught, and should be avoided. Insect densities are generally sufficient to provide large samples from early June to late August.

1. Select trap site within 1-10 m of the water's edge, clear of vegetation or any large objects that might reduce visibility of light trap from the water or surrounding shoreline. Distances up to 100 m will collect adequate numbers. Avoid areas with street lights or other bright artificial light sources.

2. Place sheet on ground or other level surface, and position bucket in the centre.

3. Place the reservoir in the bucket, and pack approximately 2 kg of dry ice, broken up into chunks (5-10 cm diameter) around reservoir.

4. Cover the bucket with the funnel, and secure funnel to the mouth of the bucket.

5. Place vanes, with UV light inserted, on top of funnel. Secure vanes to base of trap with elasticised ("bungee") chords, if necessary.

6. Connect light to batteries to turn light on at sunset. Allow light trap to operate for a minimum of 2 h, or overnight. If the number of attracted insects is large, monitor trap reservoir at 15 minute intervals and empty into collecting jars as necessary. Since mayflies do not enter the trap, they should be grasped by the wings and added to the trap reservoir, or a separate collecting jar.

7. At the end of the sampling period or in the morning, turn light off and fold up the sheet to retain any animals that did not enter the trap. Empty reservoir into sample jar. Transport collecting jars and sheet to storage location in cooler containing dry ice. Store samples and sheet at -20°C, adding animals from the sheet to the collecting jars as soon as possible.

6.1.4. Sample Sorting and Preparation for GC Analysis.

Frozen samples should be allowed to thaw at room temperature in the unopened sample jar to prevent water uptake due to condensation. A subsample of the thawed sample should be removed and preserved in 70% ethanol for taxonomic identification. To facilitate sorting, contents of the sample jar may be emptied onto a piece of hexane-rinsed aluminum foil. Taxa selected for contaminant analysis may be removed using hexane-rinsed forceps. Although initial identification of specimens will require a microscope, different families of Trichoptera may be separated without the aid of a microscope. Useful taxonomic keys for identification of aquatic insects are listed in section 2.2.2. Sufficient numbers of individuals should be removed for contaminant analysis to yield three replicate samples, each weighing 1-5 g (fresh weight). Analysis of larger (3-5 g) samples tends to yield more precise results. The sorted replicate samples should be weighed and then can be wrapped in hexane-rinsed aluminum foil, and refrozen until analysis by GC. Samples may be stored for a maximum of 245 days prior to analysis. An additional 1-5 g portion of the taxa selected for contaminant analysis should be removed and used for dry weight determination. This portion should be weighed at the same time as the GC replicate samples, dryed for at least 24 h at 100°C, and reweighed. The dry to wet weight ratio is then used to calculate the dry weights of samples used for contaminant analyses.

6.2. APPENDIX 2.

Detailed Results of Contaminant Analyses

APPENDIX 2.

Table 1. Contaminant concentrations in adult aquatic insect samples collected in 1987. All concentrations are expressed in units of $\mu g\ kg^{-1}$ (±1 S.E.) dry mass (Hept. = heptachlor, H.epox. = heptachlor epoxide, Dield. = dieldrin).

			Contaminant										
Taxon	Location	% Lipid	QCB	HCB	QCS	α-BHC	γ-BHC	Hept.	Aldrin	H.epox.	Dield.	pp'-DDE	pp'-DDT
Hydropsyche	Gull R.	15.02	ND	1.42	0.52	3.14	9.43	ND	ND	0.23	16.12	18.18	ND
(0.3 g)		(0.766)	--	(1.391)	(0.320)	(2.487)	(9.434)	--	--	(0.230)	(7.615)	(8.086)	--
Hydropsyche	Gull R.	15.02	ND	21.13	14.83	8.46	5.01	ND	ND	9.53	35.5	47.56	ND
(0.6 g)		(0.766)	--	(19.749)	(14.831)	(0.043)	(2.798)	--	--	(4.365)	(19.572)	(17.500)	--
Hydropsyche	Gull R.	15.02	ND	1.85	1.32	8.65	4.60	ND	ND	8.71	17.2	40.09	ND
(1.2 g)		(0.766)	--	(0.604)	(0.936)	(1.146)	(1.409)	--	--	(1.476)	(3.648)	(4.771)	--
Hydropsyche	Gull R.	15.02	0.22	1.81	0.12	7.73	3.57	ND	ND	7.04	18.52	29.95	6.64
(2.5 g)		(0.766)	(0.224)	(0.164)	(0.117)	(0.232)	(0.110)	--	--	(0.524)	(1.298)	(0.583)	(0.816)
Hydropsyche	Gull R.	15.02	0.60	1.82	0.11	8.26	3.30	ND	ND	7.11	16.04	26.73	7.85
(5.0 g)		(0.766)	(0.104)	(0.094)	(0.100)	(0.336)	(0.249)	--	--	(0.289)	(1.550)	(2.300)	(1.056)
Hexagenia	Windsor	20.86	7.47	166.59	116.10	17.72	51.68	ND	ND	10.55	132.73	27.93	ND
(0.3 g)	(Stn. 2)	(1.279)	(1.734)	(19.936)	(107.608)	(0.179)	(27.013)	--	--	(1.699)	(93.853)	(5.587)	--
Hexagenia	Windsor	20.86	18.19	138.49	18.41	16.72	21.27	ND	ND	12.66	35.00	31.10	ND
(0.6 g)	(Stn. 2)	(1.279)	(9.385)	(11.404)	(2.769)	(0.695)	(12.656)	--	--	(0.671)	(8.983)	(2.941)	--
Hexagenia	Windsor	20.86	11.62	140.27	24.65	15.42	12.91	ND	ND	13.41	35.03	37.43	ND
(1.2 g)	(Stn. 2)	(1.279)	(0.762)	(3.371)	(3.973)	(1.122)	(2.258)	--	--	(1.472)	(3.236)	(0.445)	--
Hexagenia	Windsor	20.86	10.70	133.51	20.37	14.86	8.65	ND	ND	12.90	35.51	29.96	0.98
(2.5 g)	(Stn. 2)	(1.279)	(0.241)	(3.690)	(0.600)	(0.907)	(0.959)	--	--	(1.289)	(4.010)	(2.503)	(0.977)
Hexagenia	Windsor	20.86	11.18	140.35	19.83	14.63	6.59	ND	ND	9.04	31.09	30.83	ND
(5.0 g)	(Stn. 2)	(1.279)	(0.171)	(0.605)	(0.692)	(0.818)	(2.267)	--	--	(4.025)	(1.558)	(2.673)	--
Caenis	Scugog L.	6.68	0.38	0.82	0.13	2.38	0.50	0.98	ND	ND	3.54	28.23	ND
		(0.827)	(0.197)	(0.062)	(0.072)	(0.881)	(0.351)	(0.985)	--	--	(0.751)	(3.489)	--
Hexagenia	Balsam L.	13.58	0.85	1.55	0.37	4.72	3.71	0.26	0.31	2.75	3.92	21.57	0.72
		(2.674)	(0.183)	(0.757)	(0.373)	(1.082)	(2.062)	(0.264)	(0.313)	(0.159)	(1.113)	(5.391)	(0.722)
Trichoptera	Ausable R.	14.10	0.05	1.12	0.82	1.49	2.27	0.10	0.08	4.65	16.75	45.91	2.20
		(0.095)	(0.046)	(0.094)	(0.676)	(0.412)	(1.340)	(0.100)	(0.083)	(1.119)	(4.447)	(31.399)	(1.416)
Hydropsyche	Gull R.	15.02	0.16	1.91	0.26	8.28	3.53	0.21	ND	7.77	22.40	26.43	8.07
(-20 °C)		(0.766)	(0.158)	(0.038)	(0.120)	(0.424)	(0.919)	(0.109)	--	(0.062)	(1.252)	(0.530)	(0.564)
Hydropsyche	Gull R.	15.02	0.59	1.94	0.13	8.79	4.01	0.11	ND	8.79	18.01	25.14	7.21
(-70 °C)		(0.766)	(0.328)	(0.092)	(0.111)	(0.122)	(0.202)	(0.110)	--	(0.761)	(2.076)	(0.869)	(0.459)
Trichoptera	R. Canard	21.63	2.39	21.37	34.83	6.49	12.70	0.63	ND	20.95	70.54	62.82	19.15
	(Stn. 1)	(0.523)	(0.089)	(0.950)	(3.954)	(0.200)	(2.209)	(0.274)	--	(1.586)	(4.224)	(3.354)	(3.201)
Trichoptera	Windsor	25.01	2.32	18.99	32.55	23.38	16.95	ND	ND	56.81	104.17	89.71	40.56
	(Stn. 2)	(2.855)	(0.082)	(1.115)	(0.514)	(1.385)	(2.253)	--	--	(1.221)	(3.751)	(2.845)	(1.866)
Hexagenia	Sombra	14.17	4.76	71.14	26.15	12.43	6.30	ND	ND	8.73	12.24	36.50	ND
	(Stn. 3)	(1.136)	(0.504)	(3.325)	(3.751)	(1.881)	(0.649)	--	--	(0.750)	(4.235)	(2.851)	--
Hexagenia	Sarnia	13.29	3.81	27.94	5.40	14.47	5.70	ND	ND	8.65	19.87	30.54	ND
	(Stn. 4)	(0.865)	(1.606)	(3.911)	(2.626)	(1.039)	(0.196)	--	--	(0.277)	(1.609)	(5.076)	--
Hexagenia	Windsor	20.86	10.24	122.20	18.81	16.71	10.26	ND	ND	14.94	31.42	32.92	ND
(-20 °C)	(Stn. 2)	(1.279)	(0.778)	(14.116)	(1.830)	(1.376)	(2.447)	--	--	(0.574)	(3.294)	(4.419)	--
Hexagenia	Windsor	20.86	11.02	133.60	17.41	18.96	11.95	ND	ND	18.24	28.52	30.57	ND
(-70 °C)	(Stn. 2)	(1.279)	(0.505)	(8.753)	(1.382)	(2.801)	(2.375)	--	--	(2.267)	(5.117)	(3.267)	--

Table 1 (continued).

Taxon	Contaminant																	
	PCB 4*	PCB 18	PCB 19	PCB 28	PCB 52	PCB 66	PCB 87	PCB 97	PCB 101	PCB 110	PCB 118	PCB 138	PCB 141	PCB 153	PCB 170	PCB 180	PCB 182	PCB 194
Hydropsyche	ND	ND	ND	0.02	ND	2.42	6.65	ND	0.12	0.90	ND	0.28	ND	0.09	ND	0.26	0.05	ND
(0.3 g)	--	--	--	(0.021)	--	(2.109)	(6.650)	--	(0.125)	(0.904)	--	(0.280)	--	(0.095)	--	(0.257)	(0.054)	--
Hydropsyche	ND	ND	14.64	ND	2.14	4.67	ND	ND	3.61	31.65	ND	2.73	ND	1.93	0.64	2.95	2.40	ND
(0.6 g)	--	--	(14.642)	--	(1.097)	(4.667)	--	--	(0.938)	(13.845)	--	(1.139)	--	(0.604)	(0.366)	(0.860)	(0.303)	--
Hydropsyche	ND	ND	ND	ND	1.85	2.35	1.53	ND	3.10	30.84	3.31	4.52	0.41	3.71	0.49	3.12	3.27	ND
(1.2 g)	--	--	--	--	(1.245)	(0.486)	(0.129)	--	(1.361)	(7.393)	(1.760)	(0.615)	(0.217)	(0.955)	(0.173)	(1.051)	(0.505)	--
Hydropsyche	ND	ND	ND	ND	1.16	2.17	0.73	0.62	2.09	7.14	1.46	4.03	0.87	2.45	1.52	3.55	2.42	0.28
(2.5 g)	--	--	--	--	(0.071)	(0.133)	(0.157)	(0.101)	(0.131)	(2.284)	(0.485)	(0.335)	(0.297)	(0.196)	(0.180)	(0.454)	(0.397)	(0.277)
Hydropsyche	ND	ND	ND	0.41	1.69	2.05	1.74	0.79	2.64	2.65	3.24	5.21	0.59	3.08	1.03	2.78	1.69	0.36
(5.0 g)	--	--	--	(0.415)	(0.287)	(0.138)	(0.385)	(0.196)	(0.249)	(0.735)	(0.202)	(0.562)	(0.119)	(0.550)	(0.233)	(0.322)	(0.187)	(0.228)
Hexagenia	ND	ND	ND	1.13	ND	5.85	35.96	ND	14.01	8.79	2.61	12.36	ND	ND	0.86	10.99	1.47	ND
(0.3 g)	--	--	--	(1.128)	--	(5.850)	(4.922)	--	(5.627)	(3.766)	(2.608)	(6.180)	--	--	(0.864)	(5.496)	(1.468)	--
Hexagenia	ND	17.13	23.86	1.57	2.07	17.18	31.20	11.66	16.43	14.95	15.02	11.99	1.84	3.69	2.05	6.61	7.41	2.34
(0.6 g)	--	(17.127)	(23.862)	(0.885)	(2.073)	(2.175)	(15.572)	(9.352)	(4.551)	(5.515)	(2.229)	(5.669)	(0.928)	(2.224)	(1.078)	(1.694)	(1.191)	(1.170)
Hexagenia	ND	11.55	ND	3.08	7.33	16.28	21.98	6.50	15.34	15.23	12.34	20.49	3.45	6.69	6.36	10.97	6.56	2.03
(1.2 g)	--	(5.775)	--	(1.370)	(0.793)	(0.744)	(11.348)	(1.371)	(1.234)	(1.247)	(0.474)	(1.846)	(0.539)	(4.431)	(0.579)	(1.336)	(0.403)	(1.014)
Hexagenia	ND	6.26	ND	2.67	7.22	13.88	18.78	3.28	11.98	11.93	11.60	16.34	2.22	9.76	3.42	10.60	4.14	1.96
(2.5 g)	--	(3.116)	--	(0.514)	(0.172)	(0.696)	(13.976)	(0.331)	(0.974)	(0.578)	(0.154)	(0.862)	(0.354)	(1.334)	(1.051)	(1.084)	(0.103)	(0.987)
Hexagenia	ND	5.63	8.89	2.51	7.03	13.41	5.32	3.49	13.05	12.29	10.77	18.19	2.05	12.67	6.17	10.44	4.30	3.01
(5.0 g)	--	(0.130)	(4.446)	(0.106)	(0.497)	(0.541)	(0.602)	(0.417)	(0.688)	(0.446)	(0.615)	(1.344)	(0.085)	(1.353)	(0.634)	(0.893)	(0.334)	(0.188)
Caenis	ND	ND	ND	1.30	3.78	6.29	1.94	0.95	10.91	5.53	5.88	24.35	4.92	18.21	8.91	23.14	12.60	2.34
	--	--	--	(0.673)	(0.187)	(1.379)	(0.284)	(0.248)	(2.188)	(1.257)	(0.975)	(4.263)	(0.906)	(3.700)	(1.705)	(3.714)	(2.779)	(0.495)
Hexagenia	ND	2.26	ND	ND	0.79	4.40	1.12	0.74	2.23	2.82	2.28	2.31	0.37	2.01	0.62	1.74	0.81	0.79
	--	(0.156)	--	--	(0.171)	(1.288)	(0.180)	(0.192)	(0.219)	(1.320)	(0.297)	(0.351)	(0.088)	(0.627)	(0.042)	(0.207)	(0.232)	(0.124)
Trichoptera	ND	0.21	ND	0.06	1.14	1.00	0.64	0.49	1.63	1.33	1.98	2.17	0.28	1.58	0.62	1.24	1.45	0.33
	--	(0.208)	--	(0.060)	(0.362)	(0.263)	(0.119)	(0.126)	(0.456)	(0.420)	(0.450)	(0.732)	(0.103)	(0.458)	(0.315)	(0.270)	(0.617)	(0.166)
Hydropsyche	ND	ND	ND	0.26	1.32	2.32	1.24	0.66	2.69	3.59	3.46	5.75	0.48	2.84	1.22	2.43	1.26	0.55
(-20°C)	--	--	--	(0.264)	(0.255)	(0.351)	(0.166)	(0.076)	(0.512)	(1.105)	(0.129)	(0.627)	(0.022)	(0.272)	(0.323)	(0.029)	(0.173)	(0.116)
Hydropsyche	ND	0.04	ND	ND	1.20	2.29	1.19	0.94	3.28	6.15	3.37	5.03	0.76	2.99	1.19	3.22	4.59	0.54
(-70°C)	--	(0.045)	--	--	(0.156)	(0.172)	(0.113)	(0.180)	(0.275)	(1.370)	(0.473)	(0.502)	(0.170)	(0.241)	(0.031)	(0.589)	(1.988)	(0.193)
Trichoptera	0.12	11.10	0.26	12.11	18.79	38.10	59.32	10.05	49.37	32.74	26.39	68.34	14.74	54.71	33.68	65.94	33.75	4.62
	(0.125)	(1.138)	(0.262)	(0.626)	(2.004)	(3.608)	(19.135)	(0.873)	(3.398)	(1.339)	(3.100)	(9.626)	(1.571)	(6.184)	(4.199)	(6.859)	(4.285)	(4.624)
Trichoptera	ND	1.57	ND	8.86	16.51	29.56	18.30	10.34	43.47	30.37	27.96	58.76	7.54	48.82	17.48	32.40	22.75	4.85
	--	(0.165)	--	(0.417)	(0.299)	(0.558)	(0.681)	(0.519)	(2.267)	(0.391)	(0.352)	(8.351)	(1.192)	(6.131)	(3.474)	(11.714)	(2.479)	(1.033)
Hexagenia	ND	3.61	ND	1.88	9.76	13.84	5.64	4.03	16.73	11.24	15.36	15.26	2.84	13.01	3.95	9.91	2.32	2.92
	--	(0.603)	--	(0.379)	(1.731)	(0.299)	(0.452)	(0.283)	(1.220)	(0.300)	(0.691)	(1.237)	(0.159)	(1.070)	(0.146)	(1.942)	(0.391)	(0.338)
Hexagenia	ND	4.69	ND	1.93	5.70	9.06	3.18	2.49	8.74	6.86	8.95	8.20	1.29	7.41	1.65	5.00	1.29	1.82
	--	(0.558)	--	(0.048)	(0.538)	(0.892)	(0.490)	(0.457)	(0.674)	(0.559)	(0.970)	(0.854)	(0.232)	(0.752)	(0.831)	(0.625)	(0.246)	(0.078)
Hexagenia	ND	11.19	ND	3.16	6.73	12.86	6.20	3.52	12.99	11.89	11.44	19.30	3.87	12.23	5.41	10.77	5.10	2.80
(-20°C)	--	(0.386)	--	(0.484)	(0.128)	(1.161)	(0.541)	(0.356)	(0.983)	(1.268)	(0.724)	(0.919)	(0.209)	(0.080)	(0.751)	(0.544)	(1.832)	(0.399)
Hexagenia	ND	7.92	ND	3.33	6.76	13.03	6.37	3.95	13.49	12.32	11.31	19.57	2.77	12.65	5.91	10.05	4.27	2.89
(-70°C)	--	(1.845)	--	(0.600)	(0.566)	(0.582)	(0.916)	(0.235)	(0.879)	(1.042)	(1.222)	(2.123)	(0.250)	(1.333)	(0.407)	(0.765)	(0.394)	(0.046)

* PCB numbering follows Ballschmiter and Zell (1980).

Table 2a. Contaminant concentrations in samples of adult aquatic insects collected in 1988. All concentrations are expressed in units of $\mu g\ kg^{-1}$ (±1 S.E.) dry mass.

			Contaminant										
Taxon	Location	% Lipid	QCB	HCB	OCS	∝-BHC	♂-BHC	Hept.	Aldrin	H.epox.	Dield.	pp'-DDE	pp'-DDT
Trichoptera	St. Marys R.	8.55	ND	ND	0.43	ND	ND	ND	ND	1.67	9.46	9.28	11.14
	(Stn. 1)	(1.280)	--	--	(0.430)	--	--	--	--	(1.669)	(2.083)	(0.594)	(5.807)
Trichoptera	St. Marys R.	10.09	ND	ND	1.27	3.46	ND	ND	ND	1.84	5.69	7.55	4.59
	(Stn. 2)	(0.115)	--	--	(1.266)	(3.463)	--	--	--	(1.844)	(3.644)	(1.439)	(3.122)
Trichoptera	St. Marys R.	11.67	ND	1.94	5.60	4.49	0.42	ND	ND	5.07	15.20	6.89	0.38
	(Stn. 3)	(0.590)	--	(0.683)	(5.176)	(1.508)	(0.419)	--	--	(0.175)	(2.115)	(1.322)	(0.234)
Trichoptera	St. Marys R.	10.98	ND	0.57	0.76	0.82	ND	ND	ND	3.43	11.73	13.78	4.87
	(Stn. 4)	(1.120)	--	(0.574)	(0.756)	(0.823)	--	--	--	(1.095)	(1.921)	(1.131)	(4.867)
Hydropsychidae	Niagara. R	18.82	0.85	7.85	0.97	7.83	4.23	ND	ND	17.66	81.05	60.68	16.81
	(Stn. 1)	(0.508)	(0.452)	(2.303)	(0.486)	(0.663)	(0.286)	--	--	(0.809)	(3.411)	(3.695)	(1.980)
Hydropsychidae	Niagara. R	17.89	0.71	6.84	1.80	3.73	2.08	ND	ND	22.21	88.93	70.00	18.37
	(Stn. 2)	(0.370)	(0.393)	(0.578)	(0.526)	(0.399)	(1.104)	--	--	(2.907)	(2.756)	(5.121)	(2.667)
Hydropsychidae	Niagara. R	22.30	1.25	7.44	1.64	9.93	3.78	ND	ND	25.27	95.47	81.46	21.06
	(Stn. 3)	(2.284)	(0.119)	(0.471)	(0.263)	(0.117)	(0.762)	--	--	(3.016)	(8.339)	(6.982)	(4.708)
Psychomyiidae	Niagara R.	14.75	1.28	4.81	0.52	2.03	ND	ND	ND	8.39	51.27	13.61	4.87
	(Stn. 3)	(2.195)	(1.277)	(1.004)	(0.523)	(2.029)	--	--	--	(0.661)	(14.629)	(0.447)	(2.648)
Leptoceridae	Niagara R.	8.03	1.41	3.72	34.21	1.21	0.01	ND	ND	3.27	4.68	32.46	4.27
	(Stn. 4)	(0.382)	(0.068)	(0.143)	(1.434)	(0.166)	(0.013)	--	--	(0.482)	(0.790)	(1.314)	(2.798)
Leptoceridae	Niagara R.	10.48	2.64	3.31	9.94	ND	ND	ND	ND	2.26	6.70	47.28	8.36
	(Stn. 5)	(0.350)	(0.376)	(0.249)	(1.864)	--	--	--	--	(0.226)	(0.863)	(6.832)	(3.608)
Hydropsychidae	Detroit R.	20.65	1.76	11.58	15.07	3.75	4.78	ND	ND	11.21	42.91	37.36	2.21
(June)	(Stn. 1)	(0.122)	(0.111)	(0.464)	(4.675)	(0.476)	(1.122)	--	--	(2.046)	(1.749)	(1.843)	(0.715)
Hydropsychidae	Detroit R.	22.40	2.86	18.65	29.29	3.27	1.03	ND	ND	6.68	42.09	50.84	5.23
(July)	(Stn. 1)	(0.116)	(0.271)	(1.168)	(3.671)	(0.850)	(1.033)	--	--	(3.342)	(1.155)	(3.540)	(2.626)
Hydropsychidae	Detroit R.	23.58	2.25	19.26	34.28	4.38	6.39	ND	ND	9.73	49.73	38.43	3.00
(Sept.)	(Stn. 1)	(0.100)	(0.118)	(1.418)	(2.899)	(0.670)	(1.480)	--	--	(0.191)	(2.748)	(4.119)	(1.516)
Hydropsychidae	Detroit R.	16.46	2.40	17.27	30.99	3.85	2.15	ND	ND	9.65	41.37	32.10	1.39
(Sept.)	(Stn. 1)	(2.524)	(0.205)	(0.938)	(1.985)	(1.274)	(1.087)	--	--	(1.369)	(8.357)	(0.863)	(1.392)
Hydropsychidae	Detroit R.	18.47	1.77	11.49	16.42	5.44	7.13	ND	ND	17.17	54.52	55.40	15.82
(June)	(Stn. 2)	(1.411)	(0.460)	(3.398)	(4.505)	(1.660)	(3.832)	--	--	(5.083)	(15.121)	(14.451)	(7.988)
Hydropsychidae	Detroit R.	20.56	1.75	15.53	27.84	3.64	5.24	ND	ND	9.11	44.43	80.64	28.09
(July)	(Stn. 2)	(0.447)	(0.134)	(1.402)	(1.617)	(1.010)	(0.181)	--	--	(2.954)	(2.016)	(2.711)	(7.799)
Hydropsychidae	Detroit R.	20.18	2.07	20.68	45.51	3.68	4.06	ND	ND	13.04	53.43	42.98	13.84
(August)	(Stn. 2)	(0.220)	(0.165)	(1.162)	(0.557)	(0.366)	(0.359)	--	--	(0.744)	(2.819)	(0.882)	(1.799)

Table 2a (continued).

Taxon	Contaminant													
	PCB 4	PCB 18	PCB 19	PCB 28	PCB 44	PCB 52	PCB 66	PCB 70	PCB 87	PCB 97	PCB 101	PCB 110	PCB 118	PCB 138
Trichoptera	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	2.07	0.73	ND	2.73
	--	--	--	--	--	--	--	--	--	--	(0.327)	(0.729)	--	(2.621)
Trichoptera	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	1.64	ND	ND	5.00
	--	--	--	--	--	--	--	--	--	--	(1.635)	--	--	(0.523)
Trichoptera	ND	ND	ND	0.07	ND	ND	1.27	0.55	0.62	ND	2.41	1.95	1.60	6.12
	--	--	--	(0.073)	--	--	(0.743)	(0.327)	(0.619)	--	(0.103)	(0.999)	(1.009)	(0.590)
Trichoptera	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	0.91	ND	ND	6.66
	--	--	--	--	--	--	--	--	--	--	(0.914)	--	--	(0.386)
Hydropsychidae	ND	3.28	ND	4.02	5.50	11.29	19.44	10.76	9.38	6.60	25.19	17.81	17.52	38.82
	--	(2.409)	--	(0.843)	(0.851)	(0.074)	(1.675)	(0.164)	(1.132)	(0.561)	(1.839)	(1.654)	(0.770)	(0.686)
Hydropsychidae	ND	2.46	ND	5.35	7.19	15.18	22.90	15.32	11.10	8.76	35.12	26.35	24.92	50.06
	--	(2.155)	--	(3.585)	(0.443)	(1.841)	(1.672)	(1.130)	(0.804)	(0.630)	(2.049)	(1.104)	(2.594)	(3.459)
Hydropsychidae	ND	3.88	ND	5.59	8.53	17.24	28.85	19.39	15.21	10.26	34.69	27.55	25.75	46.55
	--	(2.569)	--	(0.508)	(1.114)	(1.892)	(0.899)	(2.303)	(0.891)	(1.103)	(0.520)	(1.446)	(2.948)	(1.717)
Psychomyiidae	ND	ND	ND	ND	2.19	2.00	7.10	5.88	ND	3.33	18.85	7.96	12.09	21.57
	--	--	--	--	(0.251)	(0.161)	(0.822)	(0.661)	--	(0.174)	(0.185)	(1.910)	(0.641)	(0.507)
Leptoceridae	ND	ND	ND	0.59	3.27	9.13	14.42	17.49	6.23	1.61	19.39	10.11	25.63	11.76
	--	--	--	(0.589)	(0.308)	(0.455)	(0.627)	(0.978)	(0.204)	(0.090)	(1.346)	(0.470)	(1.259)	(0.679)
Leptoceridae	ND	ND	ND	1.42	2.00	6.89	9.70	9.32	4.33	1.14	16.76	7.35	15.55	13.62
	--	--	--	(0.711)	(0.594)	(1.030)	(0.852)	(0.587)	(0.241)	(0.629)	(2.876)	(0.835)	(1.339)	(1.145)
Hydropsychidae	ND	1.19	ND	5.58	8.03	12.86	18.71	11.28	11.20	6.20	23.69	21.02	20.17	47.47
(June)	--	(0.647)	--	(0.785)	(0.346)	(1.086)	(1.660)	(0.184)	(0.634)	(0.672)	(3.139)	(0.729)	(0.943)	(2.746)
Hydropsychidae	ND	3.09	ND	5.69	14.17	18.03	26.51	18.39	13.16	7.80	41.80	29.57	30.42	73.99
(July)	--	(1.340)	--	(0.628)	(2.215)	(0.942)	(1.320)	(2.101)	(0.939)	(0.197)	(1.678)	(0.204)	(1.375)	(8.687)
Hydropsychidae	ND	3.57	ND	4.28	16.45	16.06	26.07	16.62	12.80	8.20	36.92	26.84	26.38	56.56
(Sept.)	--	(2.002)	--	(1.135)	(1.935)	(1.649)	(3.690)	(2.313)	(1.236)	(0.957)	(3.472)	(2.545)	(1.256)	(4.630)
Hydropsychidae	ND	3.10	ND	6.08	14.46	14.17	24.25	15.42	10.19	7.56	33.25	23.96	22.94	53.25
(Sept.)	--	(1.568)	--	(1.266)	(0.639)	(1.054)	(0.930)	(0.526)	(0.254)	(0.261)	(2.190)	(1.232)	(1.812)	(3.358)
Hydropsychidae	ND	3.38	ND	3.99	13.22	26.30	43.15	24.24	24.39	13.83	43.28	43.64	42.27	29.99
(June)	--	(0.195)	--	(1.994)	(1.239)	(5.278)	(3.622)	(3.189)	(6.461)	(2.479)	(6.055)	(6.844)	(9.677)	(10.832)
Hydropsychidae	ND	ND	ND	5.22	11.81	15.05	26.91	15.29	13.15	8.18	45.09	32.75	87.76	86.77
(July)	--	--	--	(0.513)	(0.667)	(1.318)	(3.338)	(0.803)	(0.838)	(0.632)	(2.998)	(2.024)	(28.668)	(9.773)
Hydropsychidae	ND	1.84	ND	1.53	10.32	7.23	13.24	8.44	6.62	5.14	20.46	17.72	16.16	34.69
(August)	--	(1.841)	--	(1.525)	(0.442)	(0.316)	(0.910)	(0.316)	(0.813)	(0.207)	(1.971)	(0.796)	(0.498)	(4.564)

Table 2a (continued).

	Contaminant										
Taxon	PCB 141	PCB 151	PCB 153	PCB 170	PCB 180	PCB 182	PCB 185	PCB 194	PCB 195	PCB 201	PCB 203
Trichoptera	ND	ND	2.85	ND	2.83	2.15	ND	ND	ND	ND	ND
	--	--	(0.595)	--	(0.264)	(0.262)	--	--	--	--	--
Trichoptera	1.35	1.23	3.36	ND	4.60	2.52	ND	ND	ND	1.04	ND
	(0.090)	(1.233)	(1.772)	--	(0.091)	(0.475)	--	--	--	(1.042)	--
Trichoptera	0.57	0.59	4.86	2.33	4.58	2.12	ND	0.99	ND	1.66	0.49
	(0.204)	(0.347)	(0.417)	(0.204)	(0.438)	(0.479)	--	(0.408)	--	(0.115)	(0.189)
Trichoptera	ND	ND	5.08	0.01	4.82	2.85	ND	ND	ND	3.70	1.25
	--	--	(2.071)	(0.011)	(0.653)	(0.718)	--	--	--	(1.158)	(0.524)
Hydropsychidae	4.79	9.33	29.44	7.67	23.34	14.14	0.83	2.34	0.72	5.89	3.25
	(0.291)	(0.978)	(0.778)	(1.210)	(0.548)	(1.145)	(0.176)	(0.045)	(0.157)	(0.478)	(0.161)
Hydropsychidae	6.96	5.80	38.26	11.12	31.18	18.48	0.93	3.10	0.81	7.41	4.01
	(0.085)	(0.416)	(2.963)	(0.277)	(1.214)	(0.486)	(0.016)	(0.456)	(0.015)	(0.143)	(0.119)
Hydropsychidae	6.40	11.90	37.34	10.66	29.11	17.04	0.99	4.73	1.78	6.83	4.27
	(0.375)	(0.925)	(2.703)	(0.156)	(1.095)	(0.382)	(0.055)	(1.333)	(0.895)	(0.222)	(0.135)
Psychomyiidae	3.29	3.63	15.10	5.10	11.24	10.07	0.22	0.57	ND	2.01	1.55
	(0.264)	(2.175)	(0.561)	(0.928)	(0.854)	(0.370)	(0.223)	--	--	(1.294)	(0.647)
Leptoceridae	3.42	2.82	11.75	6.80	16.76	6.05	0.38	2.94	0.36	8.12	2.10
	(0.335)	(0.424)	(0.995)	(1.513)	(1.342)	(2.944)	(0.063)	(0.995)	(0.242)	(2.191)	(1.377)
Leptoceridae	2.60	2.37	8.81	3.35	10.33	7.84	0.14	2.81	0.48	6.05	9.06
	(0.275)	(0.987)	(1.063)	(1.819)	(0.269)	(0.900)	(0.140)	(0.286)	(0.243)	(1.179)	(7.906)
Hydropsychidae	6.21	9.36	38.06	17.49	41.74	17.93	1.67	7.49	1.77	9.17	6.19
(June)	(0.119)	(0.816)	(2.804)	(0.867)	(2.171)	(1.344)	(0.256)	(0.132)	(0.164)	(0.229)	(0.271)
Hydropsychidae	13.34	16.87	61.90	31.84	55.47	32.45	2.97	10.39	5.51	22.23	9.23
(July)	(1.965)	(1.737)	(5.852)	(7.161)	(0.075)	(5.395)	(0.423)	(2.219)	(2.424)	(5.309)	(3.539)
Hydropsychidae	9.19	13.43	34.61	22.97	52.32	26.09	2.49	9.91	2.54	12.74	8.18
(Sept.)	(1.230)	(2.088)	(2.861)	(2.091)	(3.499)	(2.387)	(0.384)	(0.853)	(0.378)	(0.922)	(0.563)
Hydropsychidae	9.02	12.07	31.95	22.75	49.00	18.99	2.13	9.70	2.65	12.67	8.35
(Sept.)	(0.873)	(1.317)	(2.563)	(1.380)	(4.648)	(6.468)	(0.216)	(1.419)	(0.389)	(1.437)	(0.701)
Hydropsychidae	8.11	14.19	51.37	17.37	39.30	19.10	1.53	5.66	1.26	6.95	5.17
(June)	(1.370)	(2.279)	(11.216)	(2.378)	(7.502)	(3.652)	(0.221)	(1.103)	(0.140)	(1.169)	(0.771)
Hydropsychidae	14.78	17.98	58.70	31.11	68.97	32.87	3.12	8.28	2.44	15.89	9.68
(July)	(2.037)	(2.533)	(15.191)	(4.124)	(8.769)	(3.842)	(0.488)	(1.203)	(0.301)	(0.441)	(1.475)
Hydropsychidae	5.06	3.03	19.13	12.72	25.38	13.46	1.04	5.41	1.82	7.40	4.23
(August)	(1.194)	(0.487)	(2.771)	(1.803)	(3.137)	(2.143)	(0.273)	(0.400)	(0.293)	(0.567)	(0.337)

Table 2b. Contaminant concentrations in samples of adult aquatic insects collected in 1988. Concentrations are expressed in units of $\mu g\ kg^{-1}$ (±1 S.E.) dry mass.

Taxon	Location	% Lipid	Contaminant										
			QCB	HCB	OCS	α-BHC	γ-BHC	Hept.	Aldrin	H.epox.	Dield.	pp'-DDE	pp'-DDT
Hydropsychidae	Detroit R.	17.81	1.48	9.59	6.55	2.68	3.79	ND	ND	13.63	52.12	120.59	37.29
(U.S. side)		(0.240)	(0.262)	(1.049)	(3.049)	(0.396)	(0.046)	--	--	(1.457)	(4.515)	(4.597)	(16.682)
Hydropsychidae	Detroit R.	12.85	1.99	9.28	10.00	3.11	3.55	ND	ND	9.70	38.96	89.18	14.12
(U.S. side)		(1.688)	(0.376)	(0.422)	(0.978)	(0.492)	(0.388)	--	--	(1.131)	(2.700)	(4.337)	(3.890)
Hydropsychidae	Detroit R.	19.74	1.69	17.56	26.16	5.15	6.71	0.66	ND	6.40	48.65	104.81	31.33
(Canadian side)	(Stn. 2)	(0.208)	(0.089)	(0.405)	(0.688)	(0.389)	(0.272)	(0.663)	--	(3.216)	(8.790)	(10.169)	(1.547)
Hydropsychidae	Detroit R.	17.68	2.58	21.43	28.38	4.61	8.17	1.03	ND	11.96	41.84	116.43	19.80
(Canadian side)	(Stn. 2)	(2.631)	(0.668)	(5.347)	(1.063)	(0.653)	(0.909)	(0.729)	--	(3.148)	(8.542)	(8.411)	(1.389)
Macrostemum	Detroit R.	19.12	3.18	14.48	15.52	6.59	3.29	1.58	ND	7.75	52.51	146.84	5.34
(U.S. side)		(1.417)	(0.838)	(0.122)	(0.741)	(0.181)	(0.310)	(1.583)	--	(1.434)	(34.957)	(12.840)	(5.344)
Macrostemum	Detroit R.	22.94	2.26	16.67	18.98	7.88	4.58	0.77	ND	1.82	25.27	150.04	13.10
(U.S. side)		(0.355)	(0.078)	(2.037)	(4.557)	(0.239)	(1.217)	(0.771)	--	(1.816)	(10.393)	(12.639)	(1.746)
Macrostemum	Detroit R.	22.54	2.78	33.96	54.59	7.33	5.50	ND	ND	6.75	11.88	55.51	10.31
(Canadian side)	(Stn. 2)	(1.405)	(0.042)	(1.281)	(3.192)	(0.386)	(0.773)	--	--	(0.303)	(0.339)	(3.684)	(1.671)
Macrostemum	Detroit R.	19.30	2.93	31.70	53.41	7.01	5.22	ND	ND	8.68	12.70	61.33	15.43
(Canadian side)	(Stn. 2)	(0.590)	(0.158)	(1.997)	(2.979)	(0.540)	(0.852)	--	--	(2.829)	(1.688)	(3.830)	(2.908)
Trichoptera	St. Clair R.	25.78	5.62	65.62	174.64	6.35	4.54	ND	ND	17.77	86.66	58.16	11.95
(June)	(Stn. 3)	(7.310)	(0.312)	(3.386)	(28.450)	(0.876)	(2.290)	--	--	(7.860)	(15.912)	(6.663)	(6.318)
Hydropsychidae	St. Clair R.	20.27	1.91	32.56	58.78	7.90	5.22	ND	ND	8.64	43.21	43.66	7.89
(July)	(Stn. 3)	(2.066)	(0.187)	(6.318)	(5.671)	(0.765)	(0.478)	--	--	(4.349)	(2.873)	(4.052)	(4.125)
Leptoceridae	St. Clair R.	9.71	1.97	18.38	142.67	1.53	4.77	ND	ND	3.89	18.84	27.64	2.33
(July)	(Stn. 3)	(0.741)	(0.175)	(1.027)	(5.242)	(0.796)	(0.542)	--	--	(1.950)	(3.953)	(3.242)	(1.169)
Trichoptera	St. Clair R.	12.07	ND	12.42	50.04	1.76	ND	ND	ND	ND	22.22	11.78	1.55
(August)	(Stn. 3)	--	--	--	--	--	--	--	--	--	--	--	--
Hydropsychidae	St. Clair R.	19.12	1.97	21.30	59.02	3.04	2.58	ND	ND	13.18	69.96	47.66	15.59
(June)	(Stn. 4)	(0.306)	(0.198)	(1.872)	(8.243)	(0.652)	(0.017)	--	--	(6.006)	(3.676)	(2.790)	(2.133)
Hydropsychidae	St. Clair R.	18.89	2.59	21.74	41.23	5.73	3.70	ND	ND	7.19	38.80	31.73	15.16
(July)	(Stn. 4)	(1.661)	(0.749)	(0.010)	(5.846)	(0.858)	(0.482)	--	--	(3.597)	(1.211)	(0.558)	(3.051)
Trichoptera	St. Clair R.	6.90	0.51	32.13	111.38	1.60	4.91	ND	ND	4.85	35.92	19.55	3.59
(August)	(Stn. 4)	(0.575)	(0.508)	(1.862)	(10.087)	(0.897)	(0.893)	--	--	(1.141)	(2.208)	(1.173)	(1.797)
Hexagenia	L. St. Clair	10.88	4.75	48.68	6.96	6.64	3.62	ND	ND	5.61	14.43	23.91	0.40
	(SW)	(1.926)	(0.649)	(3.909)	(0.961)	(0.545)	(0.630)	--	--	(0.960)	(1.154)	(0.568)	(0.401)
Hydropsychidae	L. St. Clair	18.21	1.93	13.91	19.90	2.60	5.53	ND	ND	15.16	43.47	46.15	17.12
	(SW)	(1.587)	(0.431)	(0.308)	(0.490)	(0.903)	(0.645)	--	--	(1.750)	(1.824)	(1.887)	(6.968)
Hexagenia	L. St. Clair	16.84	3.53	34.82	5.91	9.89	4.15	ND	ND	5.63	15.84	38.47	0.80
(imagoes)	(centre)	(0.440)	(0.260)	(2.439)	(1.653)	(0.242)	(0.267)	--	--	(0.237)	(0.185)	(1.899)	(0.804)
Hexagenia	L. St. Clair	16.45	8.28	73.96	8.71	8.22	0.59	ND	ND	3.92	17.06	22.91	0.46
(subimagoes)	(centre)	(1.445)	(0.235)	(4.752)	(0.671)	(0.220)	(0.590)	--	--	(1.470)	(1.063)	(1.310)	(0.457)
Hexagenia	L. St. Clair	12.62	3.94	34.91	4.39	6.28	1.54	ND	ND	4.67	13.47	21.63	0.60
(female imagoes)	(S)	(0.619)	(0.350)	(2.774)	(0.317)	(0.393)	(0.771)	--	--	(0.929)	(0.978)	(1.264)	(0.235)
Hexagenia	L. St. Clair	16.37	3.31	59.89	14.78	11.18	5.23	ND	ND	7.99	31.91	40.06	0.59
(male imagoes)	(S)	(0.448)	(0.583)	(13.561)	(4.817)	(0.515)	(0.076)	--	--	(0.241)	(2.041)	(5.021)	(0.591)

Table 2b (continued).

Taxon	Contaminant											
	PCB 4	PCB 18	PCB 19	PCB 28	PCB 44	PCB 52	PCB 66	PCB 70	PCB 87	PCB 97	PCB 101	PCB 110	PCB 118
Hydropsychidae	ND	3.57	ND	8.80	11.82	28.88	40.90	26.35	25.56	14.44	58.11	35.72	50.10
(U.S. side)	--	(0.154)	--	(0.411)	(0.082)	(2.425)	(0.394)	(0.789)	(3.439)	(1.138)	(7.302)	(22.290)	--
Hydropsychidae	ND	2.72	ND	4.68	11.06	23.83	42.28	24.70	24.67	13.80	61.28	60.44	54.46
(U.S. side)	--	(1.515)	--	(2.403)	(0.878)	(1.488)	(3.625)	(2.468)	(1.370)	(1.076)	(5.962)	(7.290)	(4.135)
Hydropsychidae	ND	4.90	ND	6.02	11.09	13.69	24.78	13.69	12.47	7.58	36.19	27.21	24.25
(Canadian side)	--	(2.186)	--	(2.953)	(1.501)	(1.222)	(2.152)	(2.271)	(0.403)	(0.417)	(1.752)	(0.999)	(2.131)
Hydropsychidae	ND	6.97	ND	5.23	10.43	13.24	23.42	13.59	11.21	7.46	32.09	27.45	21.47
(Canadian side)	--	(0.736)	--	(1.720)	(0.370)	(0.640)	(1.592)	(0.490)	(1.601)	(0.691)	(4.283)	(2.217)	(2.419)
Macrostemum	ND	ND	ND	7.91	5.82	15.52	36.86	19.88	15.57	8.78	58.27	40.84	51.22
(U.S. side)	--	--	--	(0.915)	(0.240)	(0.364)	(4.500)	(2.289)	(0.701)	(1.272)	(1.675)	(5.800)	(0.457)
Macrostemum	ND	ND	ND	9.95	6.32	14.36	40.30	20.98	12.19	8.19	52.55	41.04	43.34
(U.S. side)	--	--	--	(0.155)	(1.360)	(1.662)	(2.069)	(1.527)	(2.169)	(0.499)	(3.263)	(3.300)	(1.546)
Macrostemum	ND	ND	ND	2.23	11.77	3.98	10.83	5.89	4.47	2.40	16.72	12.56	16.20
(Canadian side)	--	--	--	(0.148)	(0.868)	(0.358)	(1.256)	(0.526)	(0.334)	(0.246)	(0.773)	(1.089)	(1.349)
Macrostemum	ND	ND	ND	2.44	11.51	4.53	12.19	6.37	4.53	3.42	17.06	15.38	16.18
(Canadian side)	--	--	--	(0.412)	(0.777)	(0.448)	(1.483)	(0.522)	(0.139)	(0.551)	(1.994)	(1.737)	(1.691)
Trichoptera	ND	ND	ND	1.50	11.87	13.38	29.53	17.56	13.07	9.41	27.90	29.83	34.85
(June)	--	--	--	(1.499)	(0.860)	(0.687)	(9.804)	(0.401)	(1.516)	(0.186)	(5.755)	(0.479)	(4.085)
Hydropsychidae	ND	0.75	ND	3.28	8.44	14.59	24.05	15.33	10.82	7.50	30.00	21.13	17.12
(July)	--	(0.749)	--	(2.633)	(5.492)	(5.963)	(5.858)	(8.526)	(2.325)	(1.306)	(3.477)	(2.315)	(9.182)
Leptoceridae	ND	ND	ND	ND	7.51	4.45	10.04	6.35	4.35	1.95	15.95	9.89	17.47
(July)	--	--	--	--	(0.243)	(0.399)	(0.463)	(0.349)	(0.226)	(0.358)	(1.262)	(1.099)	(1.209)
Trichoptera	ND	ND	ND	ND	5.00	3.40	5.50	3.14	2.61	2.14	8.97	7.51	9.11
(August)	--	--	--	--	--	--	--	--	--	--	--	--	--
Hydropsychidae	ND	0.23	ND	2.52	5.19	9.54	13.89	14.81	8.22	5.95	22.84	18.75	23.21
(June)	--	(0.230)	--	(0.524)	(0.920)	(0.942)	(0.576)	(1.019)	(0.527)	(0.226)	(1.054)	(0.499)	(1.313)
Hydropsychidae	ND	0.54	ND	3.09	4.88	8.55	12.05	10.24	6.42	4.20	19.95	13.05	17.09
(July)	--	(0.544)	--	(0.190)	(0.715)	(0.477)	(1.324)	(0.959)	(0.515)	(0.242)	(1.532)	(0.469)	(0.831)
Trichoptera	ND	1.90	ND	2.69	10.01	9.92	13.59	10.79	7.93	5.62	16.55	14.20	17.10
(August)	--	(1.902)	--	(1.820)	(3.237)	(4.014)	(3.855)	(4.109)	(0.998)	(0.755)	(2.294)	(1.385)	(1.412)
Hexagenia	ND	ND	ND	1.22	0.75	5.64	7.29	3.93	2.50	1.88	7.83	6.50	7.41
	--	--	--	(0.636)	(0.030)	(0.728)	(0.563)	(0.187)	(0.138)	(0.000)	(0.161)	(0.647)	(0.055)
Hydropsychidae	ND	0.64	ND	3.55	8.82	11.18	17.99	12.01	11.37	6.76	29.90	24.17	21.86
	--	(0.379)	--	(0.614)	(0.815)	(0.747)	(1.590)	(1.548)	(1.454)	(0.985)	(3.319)	(3.334)	(3.344)
Hexagenia	ND	4.52	ND	2.14	5.75	6.78	10.52	5.14	3.70	2.73	12.43	8.68	10.35
(imagoes)	--	(1.557)	--	(0.115)	(2.656)	(0.757)	(1.574)	(0.149)	(0.536)	(0.361)	(1.008)	(0.347)	(0.358)
Hexagenia	ND	ND	ND	ND	11.48	4.56	7.48	3.66	2.77	1.85	8.02	5.27	7.02
(subimagoes)	--	--	--	--	(0.524)	(0.234)	(0.927)	(0.926)	(0.350)	(0.231)	(0.799)	(0.600)	(0.701)
Hexagenia	ND	3.93	ND	1.56	7.95	3.94	6.47	4.07	2.83	1.63	7.51	5.79	7.68
(female imagoes)	--	(0.513)	--	(0.609)	(0.399)	(0.225)	(0.200)	(0.042)	(0.254)	(0.075)	(0.402)	(0.247)	(0.209)
Hexagenia	ND	ND	ND	1.25	14.53	6.37	11.76	5.80	5.41	3.47	14.50	10.98	14.79
(male imagoes)	--	--	--	(0.672)	(2.158)	(0.931)	(2.176)	(1.343)	(0.917)	(0.640)	(1.992)	(1.811)	(1.714)

Table 2b (continued).

Taxon	Contaminant											
	PCB 138	PCB 141	PCB 151	PCB 153	PCB 170	PCB 180	PCB 182	PCB 185	PCB 194	PCB 195	PCB 201	PCB 203
Hydropsychidae	125.73	18.04	14.73	98.27	38.80	91.72	50.27	3.24	13.25	2.85	31.75	3.48
(U.S. side)	(15.883)	(1.130)	(1.723)	(10.322)	(2.663)	(13.089)	(5.638)	(0.335)	(1.455)	(0.115)	(4.372)	(0.404)
Hydropsychidae	128.38	20.49	18.40	101.27	41.52	95.49	45.62	3.24	12.87	3.05	17.81	11.66
(U.S. side)	(19.415)	(2.889)	(0.751)	(13.153)	(6.359)	(17.200)	(4.613)	(0.459)	(1.471)	(0.326)	(1.468)	(0.939)
Hydropsychidae	63.67	10.96	16.93	39.29	23.36	55.45	22.90	2.52	4.76	1.86	9.90	7.49
(Canadian side)	(2.625)	(0.585)	(1.098)	(0.992)	(1.491)	(4.281)	(0.726)	(0.121)	(0.821)	(0.161)	(0.531)	(0.481)
Hydropsychidae	52.58	9.34	14.51	31.41	20.92	43.68	20.48	1.97	6.87	1.75	9.54	6.15
(Canadian side)	(13.484)	(2.436)	(3.858)	(8.708)	(5.760)	(15.126)	(5.683)	(0.503)	(1.602)	(0.345)	(2.003)	(1.284)
Macrostemum	85.47	14.78	16.81	52.51	28.55	60.44	25.53	2.93	8.43	2.58	16.39	9.58
(U.S. side)	(1.881)	(2.259)	(2.107)	(4.220)	(6.493)	(0.832)	(4.443)	(0.430)	(2.789)	(0.626)	(3.164)	(1.145)
Macrostemum	81.72	16.30	18.27	54.56	35.03	60.98	28.84	3.47	12.05	3.23	21.06	11.77
(U.S. side)	(2.296)	(0.621)	(1.094)	(0.028)	(1.837)	(1.514)	(0.268)	(0.084)	(1.772)	(0.121)	(1.847)	(1.276)
Macrostemum	24.61	3.28	4.35	14.60	6.78	15.54	7.69	0.83	1.89	0.70	5.92	3.07
(Canadian side)	(1.832)	(0.263)	(0.728)	(0.827)	(1.115)	(1.446)	(0.448)	(0.046)	(1.535)	(0.086)	(0.650)	(0.394)
Macrostemum	26.78	4.17	4.43	16.07	8.86	17.57	8.81	1.01	2.12	0.71	7.23	3.75
(Canadian side)	(2.727)	(0.542)	(1.465)	(0.752)	(1.527)	(1.975)	(0.766)	(0.172)	(1.385)	(0.338)	(0.806)	(0.582)
Trichoptera	40.45	3.38	2.96	34.02	12.59	20.93	9.07	ND	4.28	2.53	4.60	1.73
(June)	(5.445)	(0.204)	(0.684)	(3.537)	(4.682)	(0.969)	(1.671)	--	(0.737)	(2.274)	(0.255)	(0.881)
Hydropsychidae	37.18	4.51	5.59	30.63	10.42	21.13	12.68	0.42	2.20	0.44	5.56	1.92
(July)	(7.243)	(1.150)	(1.508)	(4.025)	(3.317)	(7.384)	(3.849)	(0.214)	(0.540)	(0.221)	(2.516)	(0.391)
Leptoceridae	19.67	3.42	4.58	10.87	5.81	10.85	8.29	0.26	4.08	ND	3.45	1.28
(July)	(1.260)	(0.343)	(1.188)	(0.945)	(0.744)	(0.902)	(0.980)	(0.136)	(0.738)	--	(0.249)	(0.102)
Trichoptera	10.01	0.85	2.07	6.59	2.66	4.73	2.92	ND	ND	ND	0.75	0.99
(August)	--	--	--	--	--	--	--	--	--	--	--	--
Hydropsychidae	25.28	2.20	1.96	21.71	5.10	13.95	6.81	ND	1.79	0.70	4.99	2.47
(June)	(0.777)	(0.121)	(0.111)	(0.197)	(0.115)	(1.197)	(0.537)	--	(0.573)	(0.128)	(0.931)	(0.804)
Hydropsychidae	20.63	2.21	3.64	17.87	6.16	13.15	5.99	0.30	1.99	0.53	2.90	1.30
(July)	(1.734)	(0.158)	(0.962)	(0.509)	(1.430)	(0.503)	(0.595)	(0.158)	(0.408)	(0.060)	(0.415)	(0.668)
Trichoptera	20.80	2.38	2.96	10.86	5.36	10.09	7.68	0.16	2.55	ND	3.99	1.97
(August)	(1.921)	(0.372)	(0.376)	(0.914)	(0.628)	(1.814)	(1.197)	(0.163)	(0.195)	--	(0.604)	(0.199)
Hexagenia	9.49	1.17	1.32	8.32	1.85	5.41	1.89	0.08	1.32	0.20	1.03	1.10
	(0.111)	(0.135)	(0.430)	(0.667)	(0.595)	(0.362)	(0.265)	(0.083)	(0.118)	(0.099)	(0.197)	(0.100)
Hydropsychidae	42.43	6.65	7.27	30.79	11.83	31.62	15.43	2.43	4.68	1.50	7.28	4.31
	(3.819)	(0.475)	(0.523)	(3.226)	(0.520)	(5.954)	(2.897)	(0.773)	(0.423)	(0.505)	(1.165)	(0.585)
Hexagenia	17.22	2.43	3.74	14.18	5.84	13.37	2.25	0.30	3.21	0.55	1.81	2.28
(imagoes)	(2.437)	(0.568)	(0.596)	(1.206)	(0.612)	(1.867)	(0.888)	(0.151)	(0.393)	(0.026)	(0.211)	(0.272)
Hexagenia	9.38	0.97	1.14	6.26	3.10	4.84	2.61	0.15	2.00	ND	ND	0.64
(subimagoes)	(0.762)	(0.046)	(0.593)	(0.353)	(0.488)	(0.279)	(0.292)	(0.154)	(1.286)	--	--	(0.643)
Hexagenia	8.72	0.95	1.32	5.82	2.07	3.82	1.48	0.08	1.07	ND	0.78	0.80
(female imagoes)	(0.644)	(0.207)	(0.137)	(0.573)	(0.144)	(0.108)	(0.252)	(0.085)	(0.160)	--	(0.070)	(0.059)
Hexagenia	20.05	2.43	3.59	13.76	5.26	10.96	4.03	0.15	2.10	0.32	2.40	2.12
(male imagoes)	(3.806)	(0.387)	(0.360)	(2.021)	(0.826)	(2.456)	(0.511)	(0.153)	(1.051)	(0.316)	(0.543)	(0.379)

Table 3. Contaminant concentrations in samples of adult aquatic insects collected in 1989. Concentrations are expressed in units of $\mu g\ kg^{-1}$ (±1 S.E.) dry mass, except where otherwise indicated (lipid wt.).

Taxon	Location	% Lipid	Contaminant										
			QCB	HCB	OCS	α-BHC	γ-BHC	Hept.	Aldrin	H.epox.	Dield.	pp'-DDE	pp'-DDT
Hydropsyche	Detroit R.	14.60	2.02	15.52	46.72	2.58	1.78	ND	ND	7.43	28.76	264.14	8.41
slossonae (adults)	(Windsor)	(0.263)	(0.293)	(1.556)	(6.413)	(0.913)	(0.670)	--	--	(0.279)	(4.150)	(46.140)	(2.072)
Hydropsyche	Detroit R.	10.20	0.30	6.36	12.03	1.30	0.74	ND	ND	2.66	7.60	54.26	ND
slossonae (larvae)	(Windsor)	(0.707)	(0.296)	(0.156)	(0.090)	(0.765)	(0.037)	--	--	(0.275)	(0.197)	(2.499)	--
Trichoptera	Detroit R.	18.48	1.87	14.24	30.91	4.82	2.59	ND	ND	8.33	27.02	107.66	8.89
(2 h sample)	(Windsor)	(0.649)	(0.167)	(0.653)	(1.972)	(0.338)	(0.095)	--	--	(0.087)	(3.191)	(3.346)	(0.802)
Trichoptera	Detroit R.	17.42	1.64	12.25	26.86	4.32	2.88	ND	ND	8.04	29.91	114.93	8.05
(overnight sample)	(Windsor)	(0.358)	(0.046)	(0.172)	(4.310)	(0.268)	(0.191)	--	--	(0.687)	(0.158)	(5.533)	(1.840)
Hexagenia	Detroit R.	20.11	8.24	78.89	14.23	8.75	3.92	ND	ND	4.88	14.54	28.05	ND
(785 days)	Stn. 2	(0.879)	(0.209)	(32.078)	(0.218)	(1.429)	(0.121)	--	--	(0.611)	(0.943)	(0.788)	--
Hexagenia	Detroit R.	18.83	9.22	113.92	12.24	6.81	2.17	ND	ND	4.66	12.33	22.01	ND
(female)	Stn. 2	(0.445)	(0.461)	(3.287)	(1.172)	(0.078)	(0.079)	--	--	(0.176)	(0.042)	(4.740)	--
Hexagenia	Detroit R.		49.91	616.44	66.28	36.85	11.75	ND	ND	25.18	66.71	119.41	ND
(female, lipid wt)	Stn. 2		(2.802)	(22.716)	(6.883)	(0.693)	(0.425)	--	--	(0.819)	(0.639)	(26.730)	--
Hexagenia	Detroit R.	21.83	11.29	139.28	15.35	7.34	2.91	ND	ND	5.75	18.32	25.25	ND
(male)	Stn. 2	(0.561)	(0.710)	(4.855)	(0.802)	(1.631)	(0.293)	--	--	(0.282)	(0.066)	(1.217)	--
Hexagenia	Detroit R.		51.92	639.75	70.58	33.35	13.39	ND	ND	26.29	84.03	116.00	ND
(male, lipid wt)	Stn. 2		(4.476)	(38.005)	(5.340)	(6.671)	(1.657)	--	--	(0.617)	(2.417)	(7.975)	--
Macrostemum	Detroit R.	15.00	1.75	18.52	34.24	2.79	1.70	ND	ND	4.24	9.89	64.78	ND
(female)	(Amherstburg)	(0.227)	(0.217)	(0.331)	(1.996)	(0.155)	(0.172)	--	--	(0.037)	(1.008)	(1.484)	--
Macrostemum	Detroit R.		11.72	123.51	227.94	18.56	11.39	ND	ND	28.55	65.81	432.26	ND
(female, lipid wt)	(Amherstburg)		(1.629)	(3.185)	(9.979)	(0.769)	(1.339)	--	--	(0.209)	(6.151)	(16.366)	--
Macrostemum	Detroit R.	16.02	1.67	15.76	54.30	0.02	1.29	ND	ND	4.43	5.20	120.86	ND
(male)	(Amherstburg)	(0.274)	(0.406)	(1.009)	(3.971)	(0.022)	(0.263)	--	--	(0.281)	(0.219)	(4.335)	--
Macrostemum	Detroit R.		10.35	98.29	338.34	0.13	8.06	ND	ND	27.74	32.42	753.82	ND
(male, lipid wt)	(Amherstburg)		(2.388)	(5.225)	(19.557)	(0.133)	(1.603)	--	--	(2.209)	(0.833)	(14.145)	--

Table 3 (continued).

Taxon	Contaminant											
	PCB 4	PCB 18	PCB 19	PCB 28	PCB 44	PCB 52	PCB 66	PCB 70	PCB 87	PCB 97	PCB 101	PCB 110
Hydropsyche	ND	15.00	57.38	13.71	68.08	129.20	260.52	150.44	212.57	233.59	355.35	319.79
siterens (adults)	--	(1.325)	(57.383)	(5.423)	(10.729)	(22.929)	(56.838)	(33.365)	(57.262)	(52.163)	(83.239)	(86.113)
Hydropsyche	ND	14.57	17.88	17.57	19.09	41.20	48.63	29.55	37.21	38.04	55.81	44.28
siterens (larvae)	--	(1.470)	(0.293)	(0.062)	(0.404)	(1.238)	(2.820)	(1.478)	(3.371)	(2.236)	(5.247)	(3.794)
Trichoptera	ND	11.70	ND	13.80	20.95	32.34	61.47	33.43	28.68	50.29	79.43	56.63
(2 h sample)	--	(2.022)	--	(2.893)	(3.989)	(6.428)	(10.243)	(8.522)	(5.988)	(4.872)	(9.618)	(7.655)
Trichoptera	ND	8.77	ND	11.56	19.75	31.53	64.59	34.48	33.01	46.51	85.17	61.79
(overnight sample)	--	(0.732)	--	(0.828)	(1.807)	(3.459)	(6.068)	(4.523)	(6.351)	(0.864)	(8.322)	(7.365)
Hexagenia	ND	4.79	ND	1.16	ND	6.11	10.44	11.47	3.47	8.80	11.51	9.87
(785 days)	--	(1.956)	--	(0.405)	--	(0.214)	(0.429)	(5.963)	(0.260)	(0.545)	(0.664)	(0.541)
Hexagenia	ND	2.21	ND	1.57	ND	4.76	8.72	4.95	2.84	6.82	8.86	7.16
(female)	--	(1.145)	--	(0.366)	--	(0.276)	(0.580)	(0.200)	(0.166)	(0.476)	(0.753)	(0.291)
Hexagenia	ND	11.98	ND	8.50	ND	25.76	47.22	26.80	15.36	36.90	48.01	38.74
(female, lipid wt)	--	(6.192)	--	(2.052)	--	(1.661)	(3.514)	(1.288)	(0.904)	(2.867)	(4.473)	(1.883)
Hexagenia	ND	1.87	ND	2.49	ND	6.70	11.27	6.73	4.48	9.06	12.03	10.82
(male)	--	(1.873)	--	(0.906)	--	(0.628)	(0.666)	(0.254)	(0.272)	(0.580)	(0.689)	(0.420)
Hexagenia	ND	8.68	ND	11.38	ND	30.79	51.75	30.86	20.46	41.63	55.18	49.64
(male, lipid wt)	--	(8.682)	--	(4.202)	--	(3.281)	(3.848)	(1.360)	(0.711)	(3.348)	(3.548)	(2.642)
Macrostemum	ND	1.15	ND	8.41	ND	9.31	22.37	12.26	6.59	18.88	28.20	17.98
(female)	--	(0.823)	--	(0.524)	--	(0.763)	(1.088)	(0.857)	(0.588)	(0.876)	(1.603)	(0.690)
Macrostemum	ND	7.55	ND	56.19	ND	62.26	149.41	81.92	43.95	126.06	188.40	120.06
(female, lipid wt)	--	(5.441)	--	(4.386)	--	(6.026)	(9.512)	(6.973)	(3.967)	(7.849)	(13.613)	(6.496)
Macrostemum	ND	0.51	ND	8.61	ND	4.50	29.54	8.44	6.74	29.08	47.50	18.61
(male)	--	(0.514)	--	(0.722)	--	(0.270)	(0.969)	(0.885)	(0.470)	(1.051)	(0.633)	(0.392)
Macrostemum	ND	3.11	ND	53.62	ND	28.02	184.35	52.70	42.18	181.38	296.49	116.19
(male, lipid wt)	--	(3,106)	--	(3,604)	--	(1,210)	(4,908)	(5,698)	(3,456)	(3,841)	(2,790)	(2,334)

Table 3 (continued).

Taxon	Contaminant												
	PCB 118	PCB 138	PCB 141	PCB 151	PCB 153	PCB 170	PCB 180	PCB 182	PCB 185	PCB 194	PCB 195	PCB 201	PCB 203
Hydropsyche	601.88	622.02	83.10	73.20	369.55	82.96	135.71	56.02	ND	15.58	4.78	17.47	12.08
alterans (adults)	(162.675)	(176.094)	(21.566)	(17.274)	(87.237)	(21.606)	(29.179)	(9.021)	--	(2.033)	(1.438)	(3.655)	(2.552)
Hydropsyche	70.44	85.09	12.82	11.40	59.14	13.24	21.25	10.48	ND	2.57	0.87	4.75	2.53
alterans (larvae)	(9.590)	(14.359)	(1.765)	(1.380)	(9.020)	(2.095)	(3.950)	(0.776)	--	(0.048)	(0.159)	(1.501)	(0.155)
Trichoptera	66.94	158.53	30.39	42.49	146.06	62.05	133.99	65.98	ND	17.70	5.90	28.71	18.34
(2 h sample)	(14.924)	(16.298)	(2.736)	(4.588)	(12.021)	(4.740)	(11.529)	(6.574)	--	(1.254)	(0.523)	(3.530)	(1.974)
Trichoptera	67.67	143.14	28.26	39.39	136.73	56.64	115.76	54.93	ND	17.13	4.55	22.54	14.72
(overnight sample)	(5.530)	(8.418)	(1.638)	(2.225)	(5.015)	(4.265)	(12.181)	(2.503)	--	(1.467)	(0.284)	(0.817)	(0.530)
Hexagenia	10.21	15.26	2.08	2.97	15.57	4.73	8.96	3.13	ND	2.68	0.42	1.72	1.76
(785 days)	(0.807)	(1.107)	(0.187)	(0.201)	(0.924)	(0.287)	(0.769)	(0.254)	--	(0.696)	(0.049)	(0.212)	(0.115)
Hexagenia	7.89	11.06	1.59	2.08	11.49	3.48	6.26	3.30	ND	2.09	0.46	1.00	1.41
(female)	(0.180)	(0.855)	(0.035)	(0.365)	(1.422)	(0.330)	(0.608)	(1.464)	--	(0.265)	(0.082)	(0.127)	(0.256)
Hexagenia	42.66	59.87	8.58	11.30	62.25	18.82	33.90	17.97	ND	11.33	2.51	5.42	7.67
(female, lipid wt)	(1.105)	(5.109)	(0.197)	(2.077)	(8.220)	(1.941)	(3.609)	(8.113)	--	(1.526)	(0.439)	(0.730)	(1.456)
Hexagenia	11.74	16.44	2.15	3.02	17.60	5.21	8.09	2.76	ND	2.99	0.62	1.41	1.85
(male)	(0.503)	(0.534)	(0.171)	(0.247)	(0.995)	(0.130)	(0.342)	(0.389)	--	(0.293)	(0.329)	(0.121)	(0.039)
Hexagenia	53.87	75.47	9.88	13.88	80.74	23.93	37.15	12.68	ND	13.74	2.85	6.49	8.50
(male, lipid wt)	(2.955)	(4.082)	(0.900)	(1.220)	(5.330)	(1.191)	(2.170)	(1.926)	--	(1.544)	(1.552)	(0.713)	(0.352)
Macrostemum	31.55	59.44	9.00	10.06	60.84	26.07	55.08	25.82	ND	11.50	3.73	18.49	10.28
(female)	(1.481)	(1.355)	(0.655)	(0.541)	(2.548)	(0.556)	(0.852)	(0.564)	--	(0.620)	(0.084)	(0.143)	(0.259)
Macrostemum	210.70	396.62	60.17	67.19	406.23	173.94	367.45	172.27	ND	76.65	24.83	123.29	68.53
(female, lipid wt)	(13.001)	(15.047)	(5.318)	(4.685)	(23.404)	(6.302)	(11.191)	(6.240)	--	(3.781)	(0.508)	(2.470)	(1.444)
Macrostemum	50.42	99.56	19.07	18.11	98.91	40.92	86.57	39.01	ND	14.12	4.74	24.56	13.21
(male)	(0.975)	(2.914)	(0.510)	(1.415)	(3.236)	(1.635)	(3.801)	(1.834)	--	(0.542)	(0.139)	(0.971)	(0.530)
Macrostemum	314.70	621.14	118.97	111.49	616.98	255.19	539.82	243.25	ND	88.05	29.59	153.19	82.38
(male, lipid wt)	(2.021)	(7.500)	(1.348)	(6.518)	(9.807)	(5.869)	(14.419)	(7.211)	--	(2.013)	(0.417)	(3.455)	(1.878)

6.3. APPENDIX 3.

Publications and presentations resulting from MOE RAC Grant 322PL

Publications

Kovats, Z.E., and J.J.H. Ciborowski. 1990. Aquatic insect adults as indicators of organochlorine contamination. J. Great Lakes Res. 15:623-634.

Conference Proceedings

Kovats, Z.E., J.J.H. Ciborowski, and S. Pernal. 1987. Biomonitoring protocols for adult aquatic insects: Collection procedures, seasonal variation and dispersal. Proc. 1987 Technol. Transfer Conf., Toronto, Ontario.

Kovats, Z.E., and J.J.H. Ciborowski. 1988. Biomonitoring protocols for adult aquatic insects: Contaminant trends, sample size and sensitivity. Proc. 1988 Technol. Transfer Conf., Toronto, Ontario.

Kovats, Z.E., and J.J.H. Ciborowski. 1989. Organochlorine contaminant burdens of adult aquatic insects collected from Great Lakes connecting channels. Proc. 1989 Technol. Transfer Conf., Toronto, Ontario.

Reports and Manuscripts

Kovats, Z.E., and J.J.H. Ciborowski. 1988. Biomonitoring protocols for adult aquatic insects: Collection procedures, seasonal variation, dispersal, and contaminant analyses. Ann. Rep. Research Advisory Committee, Ontario Ministry of the Environment. 44 p.

Kovats, Z.E., and J.J.H. Ciborowski. 1988. Biomonitoring protocols for adult aquatic insects. Semiann. Rep. Research Advisory Committee, Ontario Ministry of the Environment. 19 p.

Kovats, Z.E., and J.J.H. Ciborowski. 1989. Biomonitoring protocols for adult aquatic insects. Ann. Rep. Research Advisory Committee, Ontario Ministry of the Environment. 36 p.

Presentations

Ciborowski, J.J.H. 1989. Use of aquatic invertebrates to monitor organic contaminants in large lakes and rivers. Invited Seminar, Society of Environ. Toxic. Chem., Northeastern N.Amer. Chapter. Guelph, Ontario. January, 1989.

Kovats, Z.E., J.J.H. Ciborowski, and S. Pernal. 1987. Biomonitoring protocols for adult aquatic insects: Collection procedures, seasonal variation and dispersal. Poster presentation, 1987 Technol. Transfer Conf., Toronto, Ontario.

Kovats, Z.E., and J.J.H. Ciborowski. 1988. Collection procedure, seasonal variation, and dispersal of adult aquatic insect biomonitors. Poster presentation, 1988 meeting, North American Benthological Society, Tuscaloosa, Alabama.

Kovats, Z.E., and J.J.H. Ciborowski. 1988. Aquatic insect adults as indicators of organochlorine contamination. Invited presentation, 1988 meeting, Internat. Assoc. Great Lakes Res., Hamilton, Ontario.

Kovats, Z.E., and J.J.H. Ciborowski. 1988. Biomonitoring protocols for adult aquatic insects: Contaminant trends, sample size and sensitivity. Invited presentation, 1988 Technol. Transfer Conf., Toronto, Ontario.

Kovats, Z.E., and J.J.H. Ciborowski. 1989. Spatial trends in organochlorine contaminant burdens of adult aquatic insects collected from Great Lakes connecting channels. Oral presentation, 1989 meeting, North American Benthological Society, Guelph, Ontario.

Kovats, Z.E., and J.J.H. Ciborowski. 1989. Organochlorine contaminant burdens of adult aquatic insects collected from Great Lakes connecting channels. Invited presentation, 1989 Technol. Transfer Conf., Toronto, Ontario.

Kovats, Z.E., and J.J.H. Ciborowski. 1990. Inland dispersal of adult aquatic insects. Poster presentation, 1990 meeting, North American Benthological Society, Blacksburg, Virginia.

Papers in Preparation

Kovats, Z.E., and J.J.H. Ciborowski. Inland dispersal of adult aquatic insects. Ms. in prep.

Kovats, Z.E., and J.J.H. Ciborowski. Seasonal trends in the flight activity of adult aquatic insects of the St. Clair and Detriot Rivers, Ontario. Ms. in prep.

Kovats, Z.E., L.D. Corkum and J.J.H. Ciborowski. Spatial trends of organochlorine contaminant accumulation in adult aquatic insects of Great Lakes connecting channels. Ms. in prep.

6.4. APPENDIX 4.

Taxonomic composition of Trichoptera in 1987 samples from the Detroit and St. Clair rivers

The following tables list the relative abundance of genera of Trichoptera collected in light trap samples of Trichoptera during 1987 at stations along the Detroit and St. Clair rivers. Numbers represent percentages of a taxon identified from a random subsample of 100 animals.

6.4.2. Station 2.

Taxon	May	June					July				August			Sept		
	21	3	10	15	23	30	8	14	21	28	5	18	25	1	7	22
Psychomyiidae																
Neureclipsis													1			
Phylocentropus					1											
Polycentropus				1	1								1		1	
Hydropsychidae																
Cheumatopsyche	88	45	73	66	47	78	31	67	37	48	26	88	70	81	81	80
Hydropsyche	12	46	19	9	15	2	15	21	42	2	3	8	14	17	9	10
Macrostemum							3	6	1	2						
Potamyia								3	1							
Phryganeidae																
Banksiola						3										
Phryganea																
Molannidae																
Molanna			1													
Leptoceridae																
Ceraclea		3	4	21	27	16	48	3	15	24	2		2	1	2	
Leptocella		6	1		2	1			1	14	65		2	1		
Leptocerus																
Mystacides							3			3	2				1	
Oecetis			2	3	7					7	2	2	9		6	10
Setodes																
Triaenodes									3			2	1			

6.4.1. Station 1.

Taxon	May 26	June 8	June 15	June 23	June 30	July 8	July 14	July 21	July 28	August 5	August 18	August 25	Sept 1	Sept 7	Sept 22
Psychomyiidae															
Neureclipsis		5	1				2				2	2	1	1	
Phylocentropus		4	8		1		1					2	1	1	
Polycentropus	21	5	2	1	2		7		1	3	8	10		2	
Hydropsychidae															
Cheumatopsyche	76	66	50	83	18	51	5	63	83	32	57	51	50	52	96
Hydropsyche		12	5	8	9	18	12	20			16	20	11	4	2
Macrostemum				2	2	6		1					6		
Potamyia		3				5					1				
Phryganeidae															
Banksiola				2			1								
Phryganea				1							1				
Molannidae															
Molanna															
Leptoceridae															
Ceraclea	1	4	4	3	6	9	52	10	9	2	1		12	1	
Leptocella					10			2					1		
Leptocerus			4												
Mystacides						6	2		2	56		1	4		
Oecetis	1	1	11		50	5	14	4	5	5	9	10	7	36	2
Setodes															
Triaenodes	1		15		2		4			2	5	5	7	3	

6.4.3. Station 3.

Taxon	June	July			August		
	24	2	6	28	4	10	17
Psychomyiidae							
Neureclipsis	4		1				
Phylocentropus	8		2				
Polycentropus	6		3	3			1
Hydropsychidae							
Cheumatopsyche	32	27	38	5	1	7	11
Hydropsyche	9	49	21	3	3	3	18
Macrostemum							
Potamyia		2	5				
Phryganeidae							
Banksiola							
Phryganea							
Molannidae							
Molanna							
Leptoceridae							
Ceraclea	25	17	15	37	16	26	24
Leptocella				5	17	15	6
Leptocerus							
Mystacides	1	2	3		30	10	1
Oecetis	12	3	10	26	30	36	30
Setodes			2				
Triaenodes	3			21	3	3	9

6.4.3. Station 4.

Taxon	June 24	July 2	July 6	July 27	August 4	August 10	August 24
Psychomyiidae							
Neureclipsis							
Phylocentropus							
Polycentropus			1	1	1		
Hydropsychidae							
Cheumatopsyche	57	55	35	16	14	44	86
Hydropsyche	16	27	57	29	15	35	5
Macrostemum							
Potamyia	2	1					3
Phryganeidae							
Banksiola			1				
Phryganea							
Molannidae							
Molanna							
Leptoceridae							
Ceraclea	25	15	4	44	10	17	
Leptocella		1	1		22		3
Leptocerus							
Mystacides				3	18	1	1
Oecetis			1	6	19	3	
Setodes							
Triaenodes		1		1	1		